

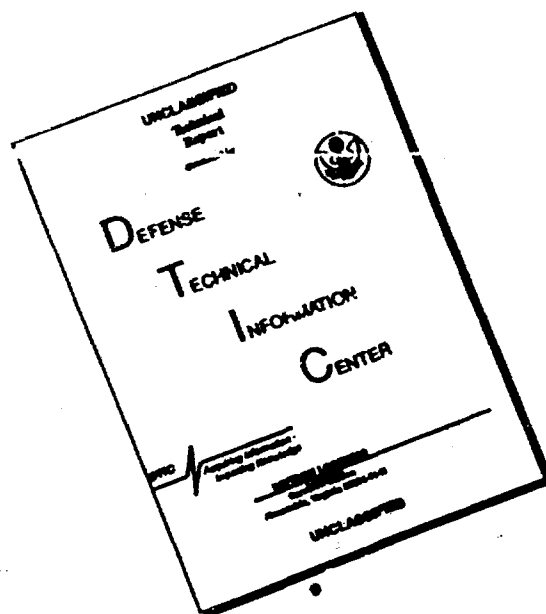
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communication satellites 1958-1992

31 DECEMBER 1991

DONALD H. MARTIN

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FOREWORD

The 34-year period following the launch of the first communication satellite by the United States has brought with it fundamental changes in the way we communicate. The development of globally connected space-based communication and data relay systems has changed the patterns of military, business, and national planners.

This document chronicles the evolution of commercial and national communications satellites during this initial 34-year period. The primary focus is on the capability of the communication payload; spacecraft details are included to convey a sense of growth in size and power of the carrier spacecraft.

The data were collected from public sources and achieved as an extra effort by a limited number of persons within The Aerospace Corporation. Earlier drafts have proven useful and informative as source material to both experts and students. This document is being provided by Aerospace as a public service to the rapidly increasing number of organizations involved with the satellite communications systems.

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PREFACE

Each type of communication satellite that has been launched or will be launched by 1992 is described. Some presently proposed satellites that may be implemented after 1992 are addressed in brief. All information presented here is based on references that were available by 20 May 1991, except that actual launch dates later in 1991 were added during proofreading.

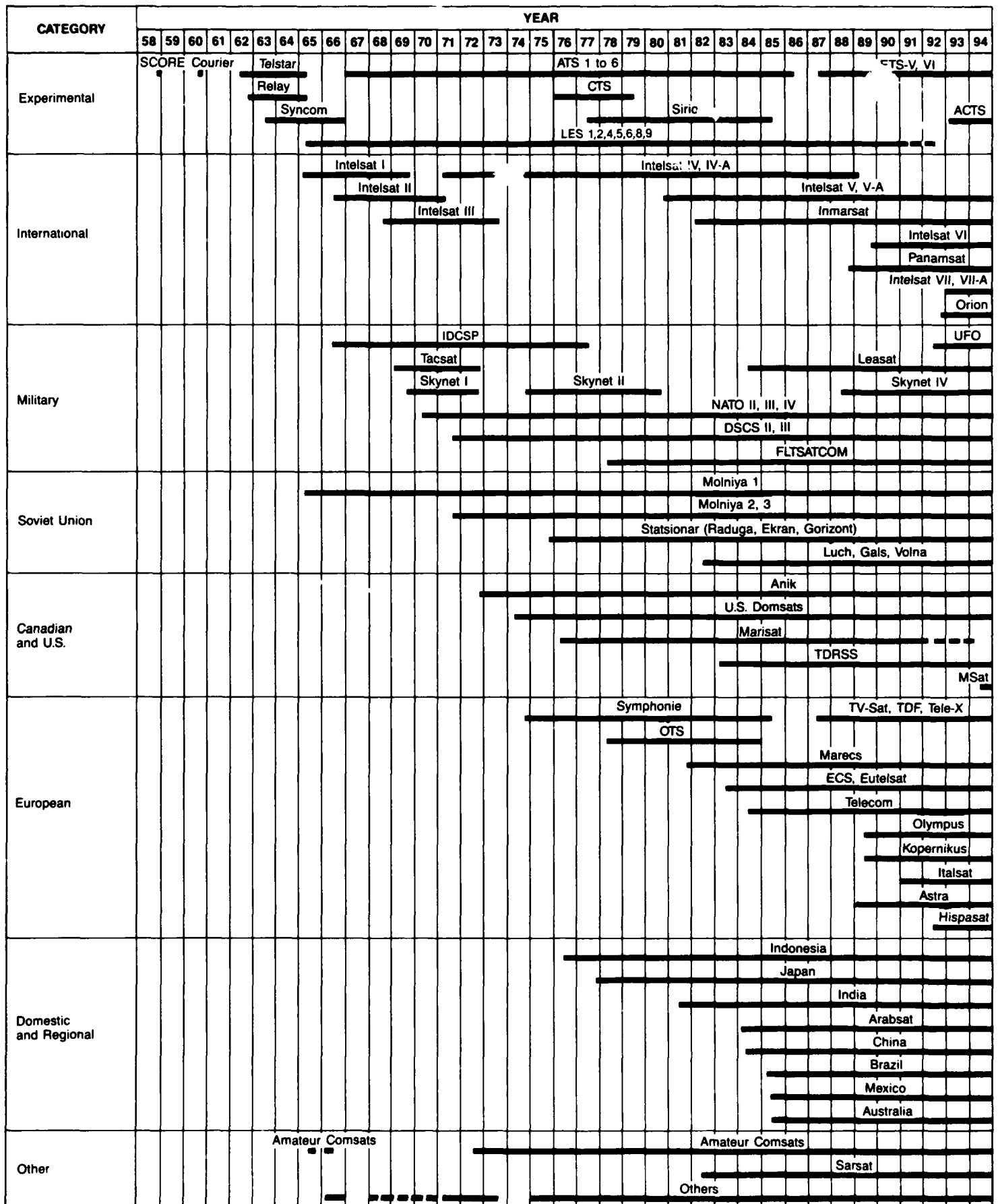
This report supersedes The Aerospace Corporation TR-0077(2790-01)-1, *Communication Satellites, 1958 to 1980*, dated 1 February 1977 (SAMSO-TR-77-76); TR-0079(4417-01)-1, *Communication Satellites, 1958 to 1982*, dated 10 September 1979 (SAMSO-TR-79-078); TR-0084A(5417-03)-1, *Communication Satellites, 1958 to 1986*, dated 1 October 1984 (SD-TR-85-76); and *Communication Satellites, 1958 to 1988*, dated 31 December 1986.

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Communication satellite programs.

INTRODUCTION

Communication satellites represent one of the most significant applications of space technology. Communication satellite experiments began early in the space age and, since 1965, satellites have been used in operational communications systems. One indication of the growth of this field is that a new communication satellite has been launched almost every year since 1965. The usefulness of communication satellites is emphasized by applications internationally, involving about 110 countries, and domestically, in over 40 countries, for communication services of all types to both large and small terminals on land and on ships. Furthermore, although some of these systems are government sponsored, others are commercial ventures that in some cases are in competition with the terrestrial communications industry.

This report describes and summarizes the technical details of each type of communication satellite for the years 1958 to 1992. An overview of the satellites covered by this report is shown. For each satellite type, the corresponding time line extends from the first launch to the end of the operation of that type. Following a brief historical survey, each major section of the report covers one of the groups indicated in the overview. Within each section, the satellite types are ordered chronologically according to their initial launch dates. Accompanying the description of each satellite is a graphic representation of the satellite, a block diagram of its communication subsystem, and a summary of details. The values given may differ from those in other documents because of the variations in definitions of the parameters (e. g., maximum versus nominal), which are not always stated. Differences also arise from the source of the value (design versus measurement) and the time point (i.e., prelaunch, beginning of life, end of life). Where

possible, these qualifying factors are stated. Somewhat less data are given for a few of the earliest satellites and also for those satellites whose designs are yet to be completed.

This report covers all types of communication satellites that have been launched as well as those in development and planning that are relatively certain to be launched. Past studies that did not result in a launch and present proposals that will not be implemented by 1992 are not described in detail, but in some cases they are mentioned in relation to more definitive programs. Although the primary objective of this report is to describe communication satellites, each satellite is only a part of a larger communication system. Therefore, for some systems, material on the earth terminals and satellite operations is presented with the satellite description.

Likely communication satellite technology and applications of the mid to late 1990s are briefly discussed. Information on international frequency allocations applicable to communication satellites is given in Appendix A. The various telemetry, tracking, and command subsystems used at the present time by communication satellites are described in Appendix B. The use of satellite beacons for atmospheric research, particularly in characterizing the atmosphere as a communications channel, is discussed in Appendix C. Symbols common to the communication subsystem block diagrams as well as abbreviations and acronyms used in the report are grouped in a glossary. An extended bibliography provides references to literature on communication satellite systems, experiments and applications, ground terminals, transmission methods, spectrum use, network engineering, satellite hardware, legal and economic issues, and other topics.

HISTORICAL BACKGROUND

The first well-known article on communication satellites was published in 1945 [1]. The article discussed the synchronous orbit and the global coverage possible with three satellites in this orbit. Some other subjects addressed included earth coverage and spot-beam antennas, multiple-beam antennas, optical and radio crosslinks between the satellites, and solar arrays for a prime power source. An approximate calculation was given for a 4-GHz downlink, concluding that 10 W of power is sufficient for a voice link with a 3-ft transmitting antenna and 1-ft receiving antenna. In 1949, another article [2] discussed the same issues and stated that a geosynchronous communication satellite could be launched as early as the end of the 1950s.

The first space communications activity can be traced back to 1946, when the Army achieved radar contact with the moon. In 1954, the Navy began communications experiments using the moon as a passive reflector. By 1959, an operational communication link was established between Hawaii and Washington, D.C. This link was available 4 to 10 hr per day until 1963, when the program was stopped, apparently because of the progress in artificial, active communication satellites.

The first man-made communication satellite, Project SCORE, was launched in December 1958. Its operating life was limited to 12 days, when the batteries failed. By 1959, many articles on communication satellite topics began to appear in the technical journals [3-9]. Typical subjects of discussion were the merits of passive versus active satellites, low versus synchronous altitude, and random orbital positions versus stationkeeping. In 1960, two journals published special issues on space electronics with more than ten articles on communications satellites. In 1962 to 1964, experimental programs using the medium-altitude Telstar and Re-

lay satellites and the synchronous-altitude Syncom satellites proved the analytical predictions about satellite communications and provided many convincing demonstrations. These programs led to the beginning of operational satellite communications in 1965 as well as to a continuing experimental effort that is still advancing the state of the art.

* * * * *

1. A. C. Clark, "Extra-Terrestrial Relays," *Wireless World*, Vol. 51, No. 10 (October 1945). Reprinted in *Communication Satellite Systems Technology, Progress in Astronautics and Aeronautics*, Vol. 19, R. B. Marsten, ed. (1966).
2. E. Burgess, "The Establishment and Use of Artificial Satellites," *Aeronautics* (September 1949).
3. J. R. Pierce, "Orbital Radio Relay," *Jet Propulsion*, Vol. 25 (April 1955).
4. J. R. Pierce and R. Kompfner, "Transoceanic Communications by Means of Satellite," *Proceedings of the IRE*, Vol. 47, No. 3 (March 1959).
5. *Space Communications and Navigation 1958-1964*, NASA SP-93 (1966).
6. L. E. Johnson, "Satellite Communications in the Navy," *Proceedings of the 6th Space Congress*, Vol. 2 (March 1969).
7. Space Electronics Issues, *Proceedings of the IRE*, Vol. 48, No. 4 (April 1960).
8. U. S. Army Space Issue, *IRE Transactions on Military Electronics*, Vol. MIL-4, No. 2-3 (April-July 1960).
9. "Communicating by Satellite," *Vectors* (Hughes Aircraft Co.), Vol. 8, No. 4 (4th Quarter 1966).

EXPERIMENTAL SATELLITES

Although the performance of communication satellites could be predicted theoretically, until 1962 or 1963 there was considerable doubt concerning whether or not their actual performance would match the theory. This was one of the basic motivations for the early communication satellite experiments. Two other important factors were the desire to prove the satellite hardware (since space technology in general was still in its infancy) and the need to test operational procedures and ground equipment. Whereas the first few experiments (SCORE, Courier, and Echo)

were very brief beginnings, the Telstar, Relay, and Syncom satellites laid definite foundations for the first operational satellites.

Communication satellites have been in operational commercial and military service since 1965 and 1967, respectively. However, there was, and still is, the need for additional experimental satellites. These are used to prove new technologies for later introduction into operational satellites. The satellites that are strictly experimental are described here. Other satellites that have combined experimental and operational objectives are discussed later; e.g., the Japanese and European programs.

SCORE

The first artificial communication satellite, called Project SCORE (Signal Communication by Orbiting Relay Equipment) [1-4], was launched in December 1958. The primary objective of the project was to demonstrate that an Atlas missile could be put into orbit. The secondary objective was to demonstrate a communications repeater.

The entire communication subsystem was developed in six months by modifying commercial equipment. Two redundant sets of equipment were mounted in the nose of the missile. Four antennas were mounted flush with the missile surface, two for transmission and two for reception. The subsystem was designed to operate for the expected 21-day orbital life of the missile. Because of the short lifetime, batteries alone were the power source; thus, the complexity of solar cells and rechargeable batteries was avoided. The details about SCORE are as follows:

Satellite

Communications equipment integral with Atlas launch vehicle
99-lb equipment
Silver-zinc batteries, 56-W maximum load

Capacity

One voice or six teletype channels
Real-time and store-dump modes

Transmitter

132 MHz, 8-W output
All vacuum tubes

Receiver

150 MHz, 10-dB noise figure
All transistors

Antenna

Four slots (two transmit, two receive)
-1 dB gain

Recorder

4-min capacity, 300- to 5000-Hz band

Design life

Two weeks

Orbit

100 × 800 nmi, 32-deg inclination

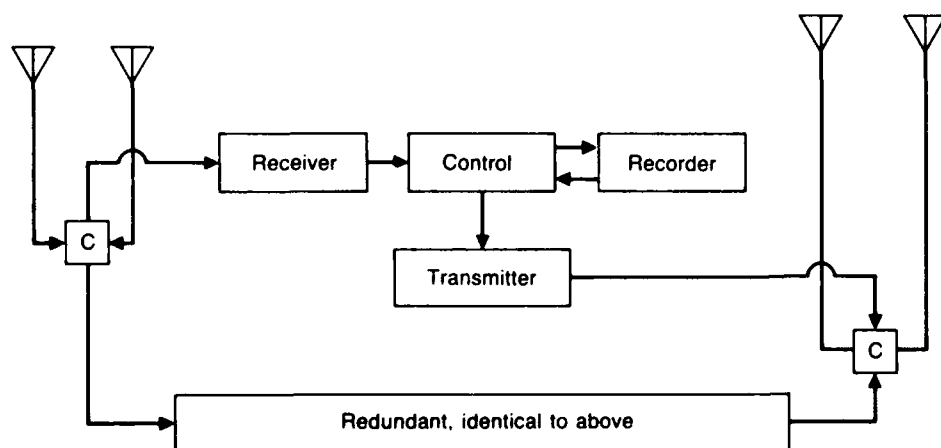
Orbital history

Launched 18 December 1958, battery failed 30 December 1958
Decayed 21 January 1959
Atlas B launch vehicle

Management

Developed by ARPA; communications equipment built by Army Signal Research and Development Laboratory, Ft. Monmouth, New Jersey

Each half of the communication subsystem had a tape recorder with a 4-min capacity. Any of the four ground stations in the



SCORE communication subsystem.

southern United States could command the satellite into a playback mode to transmit the stored message or into a record mode to receive and store a new message. A real-time mode was also available in which the recorder was bypassed. About 8 hr of actual operation occurred before the batteries failed. During this time, voice, single-channel teletype, and frequency-multiplexed six-channel teletype signals were transmitted to the satellite, recorded, stored, and later retransmitted. One of the signals handled in this manner was a Christmas message from President Eisenhower. In addition to the stored mode transmissions, there were several real-time transmissions through the satellite.

* * * * *

1. S. P. Brown and G. F. Senn, "Project SCORE," *Proceedings of the IRE*, Vol. 48, No. 4 (April 1960).
2. S. P. Brown, "Project SCORE: Signal Communication by Orbiting Relay Equipment," *IRE Transactions of Military Electronics*, Vol. MIL-4, No. 2-3 (April-July 1960).
3. M. I. Davis and G. N. Krassner, "SCORE - First Communication Satellite," *Journal of the American Rocket Society*, Vol. 4 (May 1959).
4. S. P. Brown, "The ATLAS-SCORE Communication System," *Proceedings of the 3rd National Convention on Military Electronics* (June 1959).

ECHO

During the late 1950s and early 1960s, the relative merits of passive and active communication satellites were often discussed. Passive satellites merely reflect incident radiation, whereas active satellites have equipment that receives, processes (may be only amplification and frequency translation, or may include additional operations), and retransmits incident radiation. At the time of Project Echo, the main advantages given for passive satellites were

- Very wide bandwidths.
- Multiple access capability.
- No chance for degradations due to failures of satellite electronics.

The disadvantages were

- The lack of signal amplification.
- The relatively large orbit perturbations resulting from solar and atmospheric effects (because of the large surface-to-weight ratio).
- The difficulty in maintaining the proper reflector shape.

The progress in active satellites soon overshadowed the possible advantages of passive satellites, and interest in passive satellites ceased in the mid-1960s. In the mid-1970s, there was some interest in passive satellites concerning their use in a nuclear war environment.

Project Echo [1-8] produced two large spherical passive satellites that were launched in 1960 and 1964. The details of Echo are as follows:

Satellite

1: sphere, 100 ft dia., 166 lb

2: sphere, 135 ft dia., 547 lb

Not stabilized

Aluminized mylar surface, maximum reflectivity 98% for frequencies up to 20 GHz

Frequencies used

1: 960 and 2390 MHz

2: 162 MHz

Orbit

1: 820 × 911 nmi, 48.6-deg inclination (initial values)

2: 557 × 710 nmi, 85.5-deg inclination (initial values)

Orbital history

1: launched 12 August 1960, decayed 25 May 1968

2: launched 25 January 1964, decayed 7 June 1969

Delta launch vehicle

Management

Developed by G. T. Schjeldahl Company (balloon), Grumman (dispenser) for NASA Langley Research Center (1), NASA Goddard Space Flight Center (2).

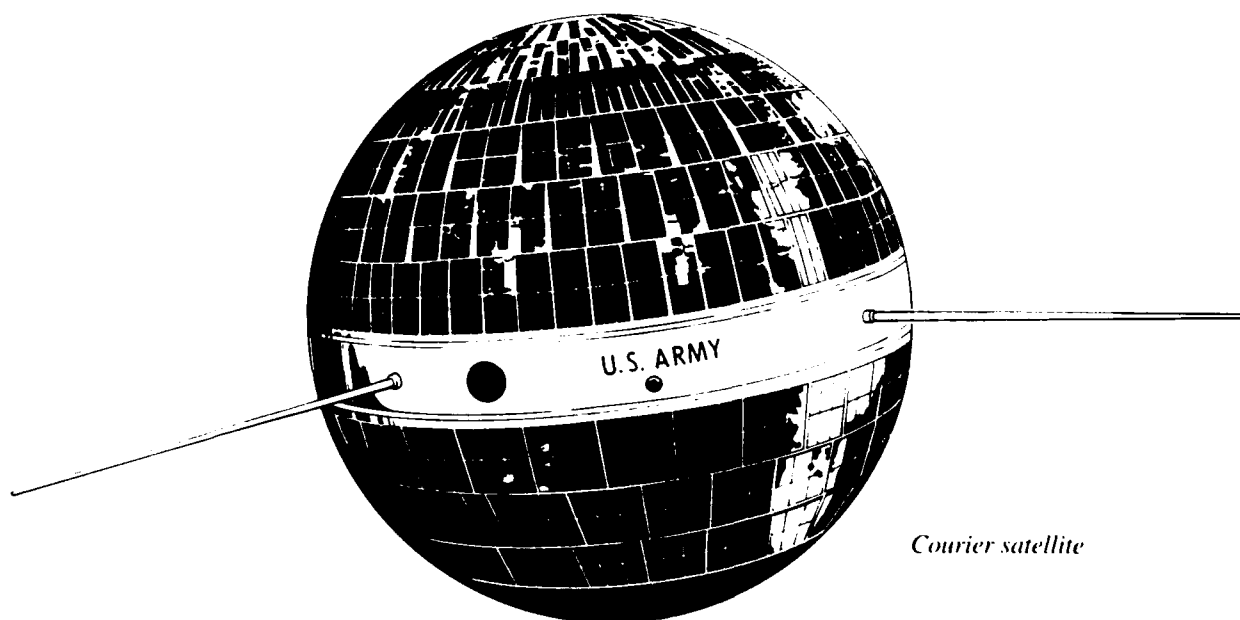
Echo 1 was used for picture, data, and voice transmissions between a number of ground terminals in the United States. In addition, some transmissions from the United States were received in England. A number of modulation methods were tested during the Echo 1 experiments, and valuable experience was gained in the preparation and operation of the terminals, especially in tracking the satellites. In addition to the communications experiments, Echo 1 was used for radar and optical measurements, and its orbital data were used to calculate atmospheric density.

Echo 2 had a slightly different design to provide a stiffer and longer lasting spherical surface. It was used very little for communications, although some one-way transmissions were made from England to the Soviet Union, but it was used in other scientific investigations similar to those performed with Echo 1.

* * * * *

1. *Space Communications and Navigation 1958-1964*, NASA SP-93 (1966).
2. Special Issue on Project Echo, *Bell System Technical Journal*, Vol. 40, No. 4 (July 1961).
3. Satellite Communications (Military-Civil Roles and Relationships), second report by the Committee on Government Operations, U.S. House of Representatives, House Report No. 178 (17 March 1968).
4. H. S. Black, "Latest Results on Project Echo," *Advances in the Astronautical Sciences*, Vol. 8 (1961).
5. J. R. Burke, "Passive Satellite Development and Technology," *Astronautics and Aerospace Engineering*, Vol. 1, No. 8 (September 1963).
6. L. Jaffe, "Project Echo Results," *Astronautics*, Vol. 6, No. 5 (May 1961).
7. W. C. Nyberg, "Experiments to Determine Communication Capability of the Echo II Satellite," *Publications of Goddard Space Flight Center 1964*, Vol. II.
8. A. Wilson, "A History of Balloon Satellites," *Journal of the British Interplanetary Society*, Vol. 34, No. 1 (January 1981).

COURIER



The objective of the Courier program [1-3] was to develop a satellite of higher capacity and longer life than SCORE, which could be used for communication tests and assessments of traffic handling techniques. The concept was similar to SCORE in that the primary operating mode was store-and-dump using on-board tape recorders. A real-time mode was also available. Unlike SCORE, Courier was a self-contained satellite and had both solar cells and rechargeable batteries for power supply. Except for the final amplifiers of the transmitters, the electronics were all solid state. The details of Courier are as follows:

Satellite

Sphere, 51 in. dia.

500 lb in orbit

Solar cells and NiCd batteries, 60 W

Capacity

Real time: one voice channel

Store-dump: 13.2 Mb/recorder digital, 4-min voice

Transmitter

1700- to 1800-MHz band

Two transmitters on, two standby

Solid state except output tubes

2-W output per transmitter

Receiver

1800- to 1900-MHz band

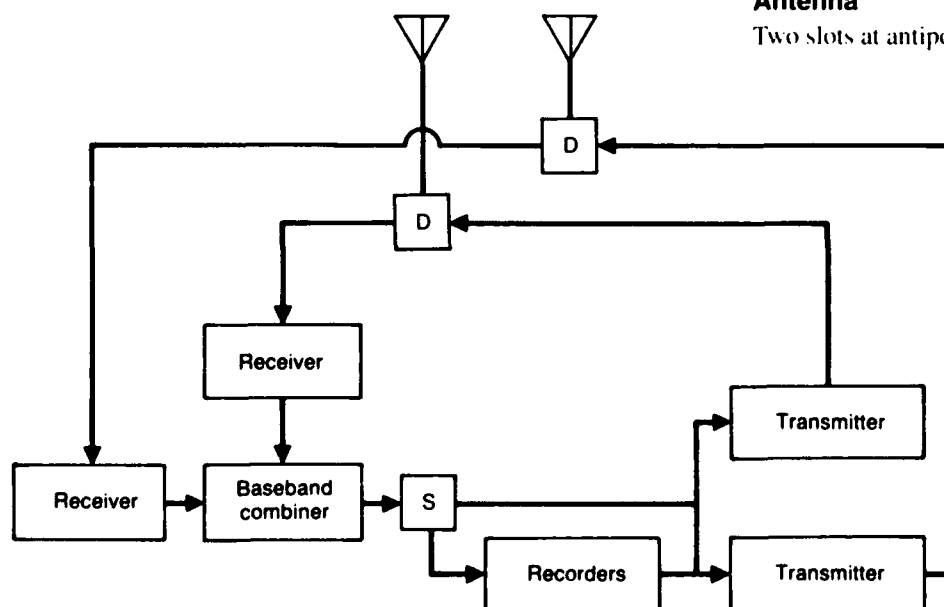
Two receivers on, two standby

All solid state

14-dB noise figure

Antenna

Two slots at antipodal points, used for both transmit and receive



Courier communication subsystem.

-4 dB gain
Linear polarization

Recorders

Four digital: each 4 min at 55 kbps (13.2 Mb total)
One analog: 4-min capacity, 300 to 50,000 Hz

Design life

One year

Orbit

525 × 654 nmi, 28-deg inclination

Orbital history

1A: launch vehicle failure
1B: launched 4 October 1960, operated 17 days
Thor-Able Star launch vehicle

Management

Developed by Army Signal Research and Development Laboratory

The Courier communication subsystem had four receivers, two connected to each antenna. Signals received through the two antennas were summed in a baseband combiner. The satellite could support a single half-duplex voice circuit in the real-time mode. One analog and four digital recorders, each with a 4-min recording capability, were used for the store-and-dump mode.

This allowed any ground terminal to use the satellite for transmission of four separate digital (multiplexed teletype) messages, one to each of four other terminals. Upon command, a recorded message (or the received signal in the real-time mode) would modulate two transmitters, one connected to each antenna. The satellite also had two spare transmitters. The two carrier frequencies were separated about 20 MHz. Various signal-combining techniques were used at the ground to make use of these two signals.

The first Courier launch was unsuccessful because of a booster failure. The second, in October 1960, was a success. Communication tests were performed by two ground terminals, located in New Jersey and Puerto Rico. The satellite performed satisfactorily until 17 days after the launch, when communications were stopped by a command system failure.

* * * * *

1. G. F. Senn and P. W. Siglin, "Courier Satellite Communication System," *IRE Transactions on Military Electronics*, Vol. MIL-4, No. 4 (October 1960).
2. P. W. Siglin and G. F. Senn, "The Courier Satellite," *Communication Satellites, Proceedings of a Symposium Held in London*, L. J. Carter, ed. (1962).
3. E. Imboldi and D. Hershberg, "Courier Satellite Communication System," *Advances in the Astronautical Sciences*, Vol. 8 (1961).

WEST FORD

The West Ford concept [1-3] grew out of a 1958 summer study on secure, hard, reliable communications. The conclusions reached were the following:

- Use satellites and microwave frequencies for long distance communications.
- Put all active equipment on the ground for reliability.
- Use a belt of dipoles instead of a single satellite for hardness.

When the concept was defined openly, there was some adverse reaction because of the uncertain effects on optical and radio astronomy. After some time, the project was allowed to proceed under certain restrictions.

West Ford and Echo were the only two passive communication reflectors put into orbit. Echo could rightly be called a satellite, but the West Ford reflector consisted of 480 million copper dipoles. The length was chosen to correspond to a half wavelength of the 8-GHz transmission frequencies used in the program. Other West Ford details are as follows:

Satellite

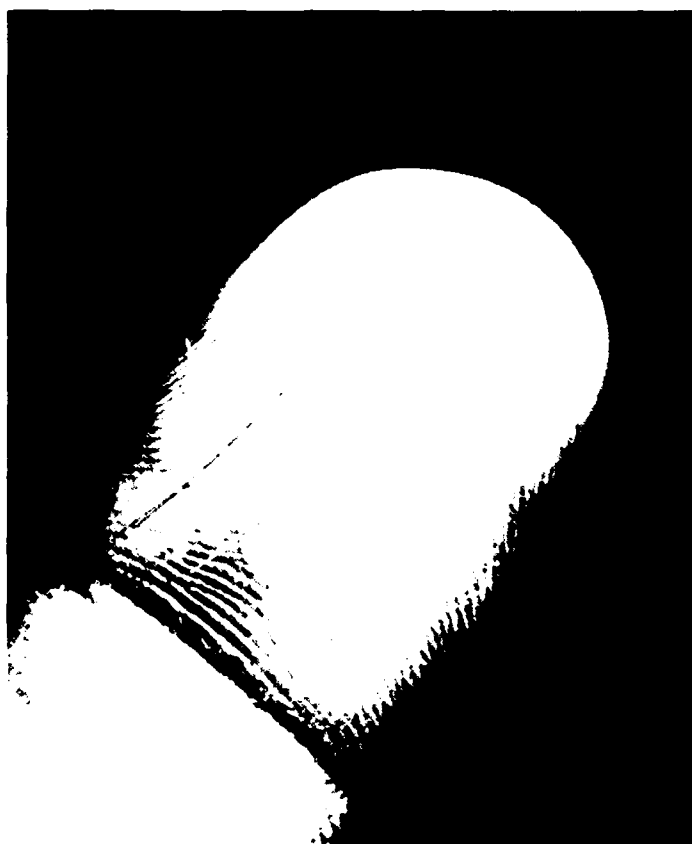
80 million copper dipoles, each 0.72 in. long, 7×10^{-4} in. dia.
88-lb dispenser plus dipoles; 43-lb dipoles

Frequencies used

7750, 8350 MHz

Orbit

1970-nmi nominal altitude
Nearly circular, nearly polar
Dispersion: 8 nmi cross-orbit, 16 nmi radially, 1300 ft average distance between dipoles



West Ford dipoles.

Orbital history

First: launched 21 October 1961, dispenser did not release dipoles

Second: launched 9 May 1963, fully dispersed August 1963

Atlas-Agena B launch vehicle

Management

Developed by MIT Lincoln Laboratory

The dipoles were dispensed from an orbiting container in May 1963. At first, all were concentrated in one portion of the orbit. During the first few weeks, voice and frequency shift keying (FSK) data up to 20 kbps were transmitted from Camp Parks (Pleasanton, California) to Millstone Hill (Westford, Massachusetts—the source of the project name). Four months later, when the belt was fully extended, the density was much lower, and only

100 bps data were transmitted. Because of this low capacity and the increasing performance of active satellites, no further experiments of this type were attempted. The last transmission of signals was accomplished in 1965, and a combination of measurements and analytic predictions indicated that all the dipoles would reenter the atmosphere before the end of the 1960s.

* * * * *

1. Special Issue on Project West Ford, *Proceedings of the IEEE*, Vol. 52, No. 5 (May 1964).
2. I. I. Shapiro, "Last of the West Ford Dipoles," *Science*, Vol. 154 (16 December 1966).
3. W. W. Ward and F. W. Floyd, "Thirty Years of Research and Development in Space Communications at Lincoln Laboratory," *The Lincoln Laboratory Journal*, Vol. 2, No. 1 (Spring 1989).

TELSTAR

The Telstar experiment [1-7] grew out of the Bell Systems' interest in overseas communication. Bell Telephone Laboratories was a major participant in communication experiments using Echo 1. The positive results of those experiments strengthened the interest in satellite communications generated by earlier analytical papers. Therefore, American Telephone and Telegraph Company (AT&T) decided to build an experimental active communication satellite. The objectives of the Telstar program were:

- To look for the unexpected.
- To demonstrate transmission of various types of information via satellite.
- To build a large ground antenna and learn how to use it.
- To gain experience in satellite tracking and orbital predictions.
- To study Van Allen radiation belt effects.
- To face the design problems required for a spaceborne repeater.

An active satellite was decided on, because the required balloon size for television bandwidths was much beyond the state of the art. The choice of the Delta launch vehicle provided basic design constraints such as size, weight, and orbit. In accordance with the fifth objective, the satellite contained a number of sensors to make radiation measurements. The third objective was accomplished by the construction and use of a ground station at Andover, Maine.

Two Telstar satellites were produced. The satellites were 34.5-in. diameter spheres with solar cells covering most of the outer surface. The solar array output alone could not support operation of the communication subsystem, so batteries were used to supply the peak power requirements. The batteries were recharged during the periods when the satellite was not in view of the ground terminals and the communication subsystem was turned off. This subsystem had a single channel with a 50-MHz bandwidth. The program details are as follows:

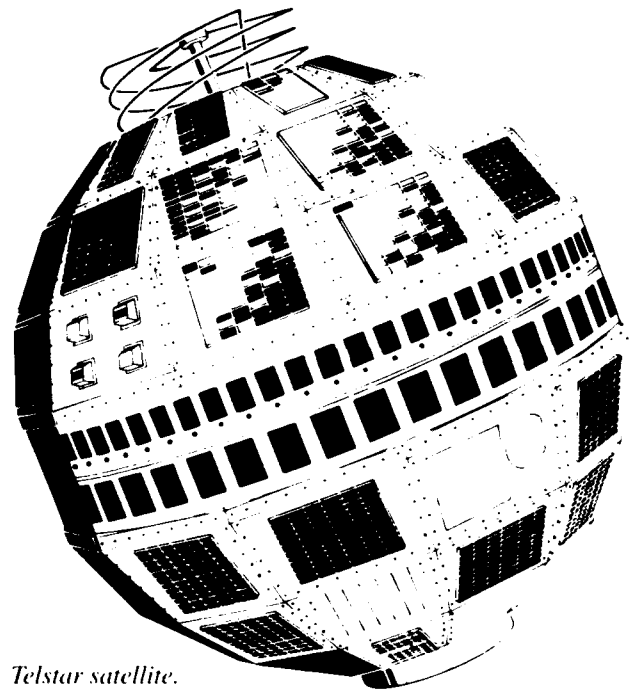
Satellite

Sphere, 34.5-in. dia.

170 lb in orbit (1), 175 lb in orbit (2)

Solar cells and NiCd batteries, 15 W

Spin-stabilized, 200 rpm



Telstar satellite.

Configuration

One 50-MHz bandwidth double-conversion repeater

Capacity

600 one-way voice circuits or one TV channel

60 two-way voice circuits (tests limited to 12 circuits by ground equipment)

Transmitter

4170 MHz

All solid state except TWT

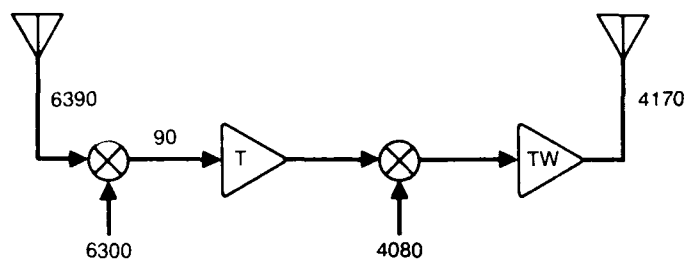
TWT operated linear at 3.3 W (saturated power: 4.5 W)

Receiver

6390 MHz

All solid state

12.5-dB noise figure



Telstar communication subsystem.

Antenna

Transmit: 48 small ports equally spaced around satellite waist

Receive: 72 small ports

Uniform pattern around waist and ± 30 deg from waist plane

Circular polarization

Design life

Two-year goal

Orbit

1: 514×3051 nmi, 45-deg inclination

2: 525×5830 nmi, 43-deg inclination

Orbital history

1: launched 10 July 1962, operated until 23 November 1962, and 4 January to 21 February 1963

2: launched 7 May 1963, operated until May 1965

Delta launch vehicle

Management

Developed by Bell Telephone Laboratories for AT&T

Telstar 1 was launched in June 1962. In the following six months, about 400 transmission sessions were conducted with

multichannel telephone, telegraph, facsimile, and television signals. In addition, over 250 technical tests and measurements had been performed. Stations in the United States, Britain, and France participated in these activities. In November 1962, the command subsystem on the satellite failed. The cause was later established as degradation of transistors due to Van Allen belt radiation. Various operations effected a recovery that allowed the satellite to be used for another month and a half early in 1963, after which the command subsystem failed again.

Telstar 2 was nearly identical to Telstar 1. The only significant design change was the use of radiation-resistant transistors in the command decoders. The Telstar 2 satellite orbit had a higher apogee than Telstar 1, which increased the time in view of the ground stations and decreased the time in the Van Allen belts. Telstar 2 was launched in May 1963 and operated successfully for two years.

* * * * *

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2. Special Telstar Issue, *Bell System Technical Journal*, Vol. 42, No. 4 (July 1963). Reprinted as *Telstar I*, NASA SP-32, Vols. 1-3 (July 1963) and Vol. 4 (including Telstar II supplement) (December 1965).
3. K. W. Gatland, *Telecommunication Satellites*, Prentice Hall, New York (1964).
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RELAY

The Relay program [1-7] was undertaken by the National Aeronautics and Space Administration (NASA) to perform active satellite communications and to measure Van Allen belt radiation and its effect on satellite electronics. Basic objectives were to transmit telephone and television signals across the Atlantic and to transmit telephone signals between North and South America. During the time the satellite was being developed, foreign governments were invited to participate in communications experiments. Primary ground stations were in Maine, England, and France—the same stations that conducted demonstrations with Telstar 1. Other ground stations were in California, New Jersey, Germany, Italy, Brazil, and Japan.

The Relay satellite had a more complex communication subsystem than Telstar, with two identical redundant repeaters. Either repeater could be connected to the common antennas by ground command. Each repeater had one 25-MHz channel and two 2-MHz channels. These channels allowed either one-way transmission of wideband signals or two-way transmission of narrowband signals. The communication subsystem block diagram is shown; the satellite details are as follows:

Satellite

Octagonal prism, 35 in. long, 29 in. dia. (53 in. overall length)

172 lb in orbit

Solar cells and NiCd batteries, 45 W

Spin-stabilized, 150 rpm

Configuration

Two double-conversion repeaters (one on, one standby), each with one wideband and two narrowband channels

Capacity

Wideband: 300 one-way voice circuits or one TV channel

Narrowband: 12 two-way telephone circuits (limited by ground equipment, not satellite bandwidth)

Transmitter

4164.7, 4174.7 MHz (NB), 4169.7 MHz (WB)

All solid state except TWT

10-W output

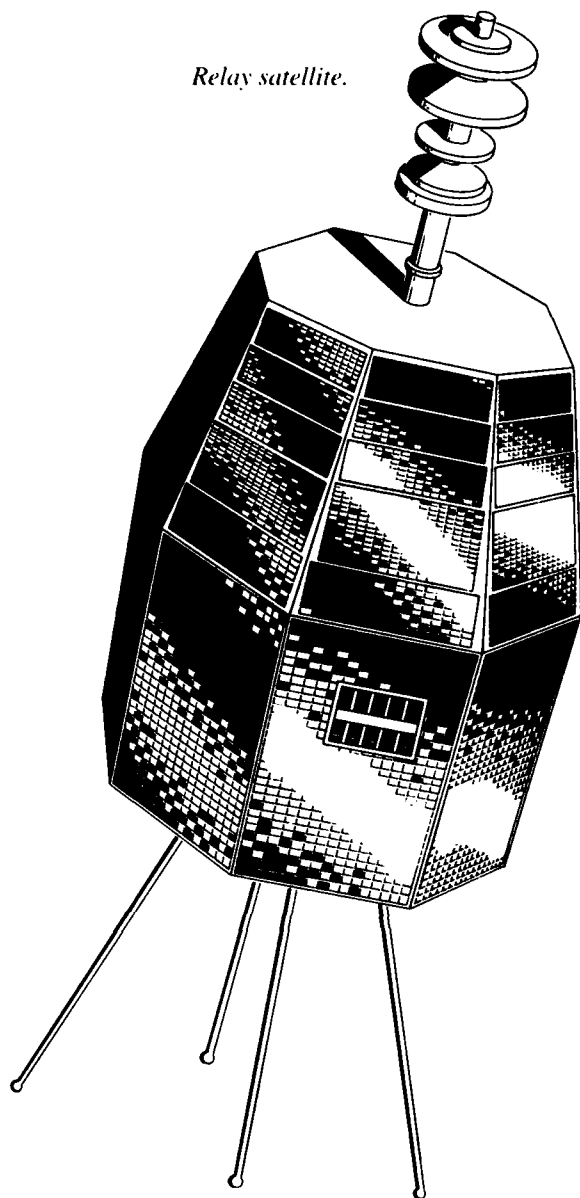
Receiver

1723.3, 1726.7 MHz (NB), 1725 MHz (WB)

All solid state

14-dB noise figure

Relay satellite.



Antenna

Two biconical horns (one transmit, one receive)
Approximately 0 dB gain normal to spin axis
Circular polarization

Design life

One year

Orbit

1: 712×4012 nmi, 47.5-deg inclination
2: 1130×4000 nmi, 46-deg inclination

Orbital history

1: launched 13 December 1962, operated until February 1965
2: launched 21 January 1964, operated until May 1965
Delta launch vehicle

Management

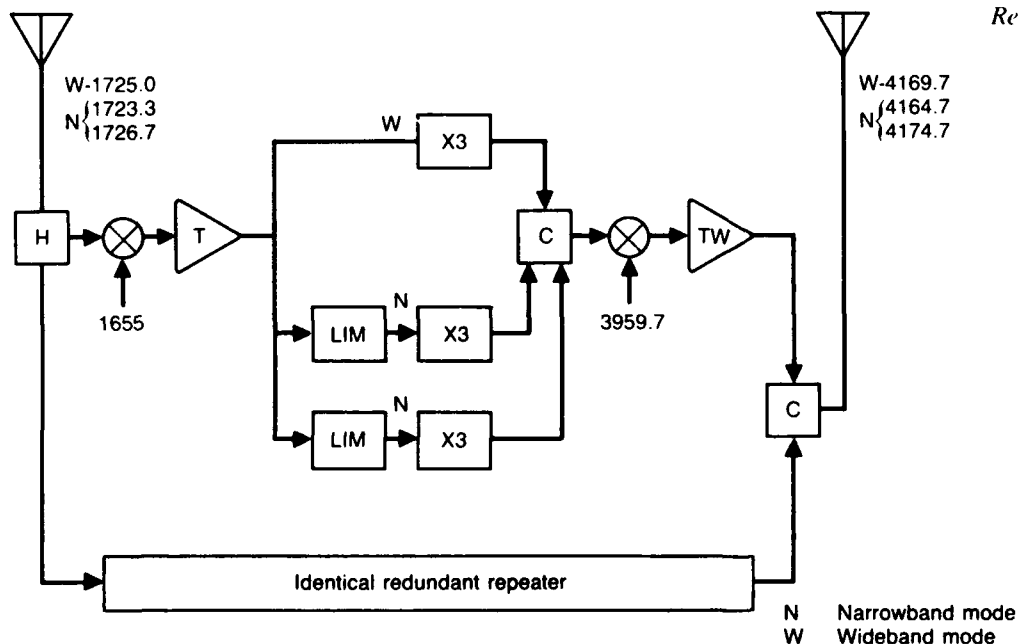
Developed by RCA for NASA Goddard Space Flight Center

Relay 1 was launched in December 1962. Radiation experiment data were obtained on the first day. That same day, difficulties with communications transponder No. 1 that caused excessive power consumption were noticed. The problem could not be fully corrected, and from January 1963 transponder No. 2 was used for almost all the communication experiments. Relay 1 operated until February 1965.

During 1963, several tests and demonstrations were conducted including telephone and television transmissions. Network TV broadcasts were transmitted from the United States to Europe and to Japan. Several times, both television and telephone transmissions were used for international medical consultations. In October 1964, television coverage of the Olympic Games was relayed from Japan to the United States by Syncom 3 and then from the United States to Europe by Relay 1.

Relay 2 was modified slightly to provide increased reliability and radiation resistance. Relay 2 was launched in January 1964 and was used in a variety of communications tests similar to those done with Relay 1. By July 1964, Relays 1 and 2 had been used for 112 public demonstrations of telephone and television transmission. Relay 2 was used until May 1965.

Relay communication subsystem.



The Telstar and Relay programs were both considered successful. They demonstrated that the technology at that time could produce a useful, medium-altitude communication satellite. In addition, ground station technology was proven, and routine operation of ground stations was demonstrated. Measurements of communications parameters indicated no significant deviations from theoretically expected values. Finally, it was shown that satellite communication systems could share frequencies with terrestrial microwave systems without mutual interference.

* * * * *

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2. K. W. Gatland, *Telecommunication Satellites*, Prentice Hall, New York (1964).

3. *Final Report on the Relay 1 Program*, NASA SP-76, Goddard Space Flight Center (1965).
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 - b. R. H. Pickard, "Relay 1 Spacecraft Performance."
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7. "Development of the Relay Communications Satellite," *Interavia*, Vol. 17 (June 1962).

SYNCOM 1 to 3

In the early 1960s, both medium and synchronous altitude communication satellites were of interest to planners. NASA conducted experiments at both altitudes using the Relay and Syncom satellites. The Syncom program [1-9] had three major objectives:

- To place a satellite in synchronous orbit.
- To demonstrate on-orbit stationkeeping.
- To make engineering measurements on a synchronous altitude communication link.

The Syncom satellite had a short cylindrical body that was spun about its axis to provide stabilization in orbit. The antennas were mounted beyond one end of the body and were colinear with the satellite axis. All the satellite equipment was contained within the body. This design formed the basis for several later synchronous altitude satellites. The communication subsystem had two receivers and two transmitters for redundancy; either receiver could be operated with either transmitter. The channelization was similar to Relay, with two 500-kHz channels for narrowband two-way communications and one 5-MHz channel for one-way wide-band transmissions. (These capabilities could not be used simultaneously.) The satellite details are as follows:

Satellite

Cylinder, 28-in. dia., 15-in. height

86 lb in orbit, beginning of life

Solar cells and NiCd batteries, 28 W initially, 19 W minimum after one year

Spin-stabilized

Solid rocket motor for apogee maneuver, cold gas propulsion for on-orbit use

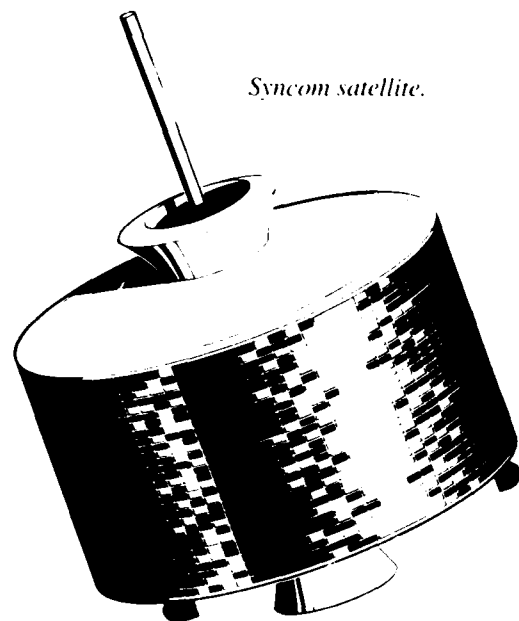
Configuration

1, 2: two 500-kHz bandwidth double-conversion repeaters, or one 5-MHz bandwidth double conversion repeater

3: one 5-MHz bandwidth and one switchable (50-kHz or 10-MHz) bandwidth double-conversion repeater (some references say 13-MHz instead of 10-MHz)

Capacity

Several two-way voice circuits or one TV channel



Syncom satellite.

Transmitter

1815 MHz

Two TWTs (one on, one standby)

2-W output

Receiver

7363 MHz

10-dB noise figure

Antenna

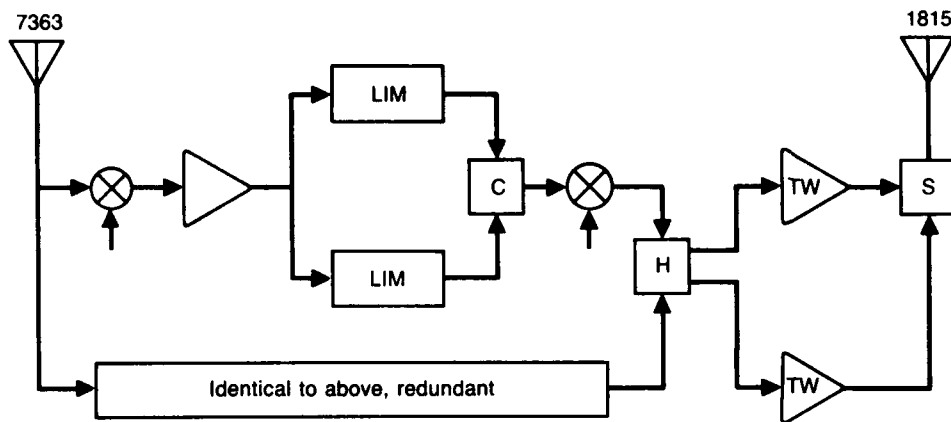
Transmit: three-element colinear slotted array, 6-dB gain, 23- x 360-deg beam

Receive: slotted dipole, 2-dB gain

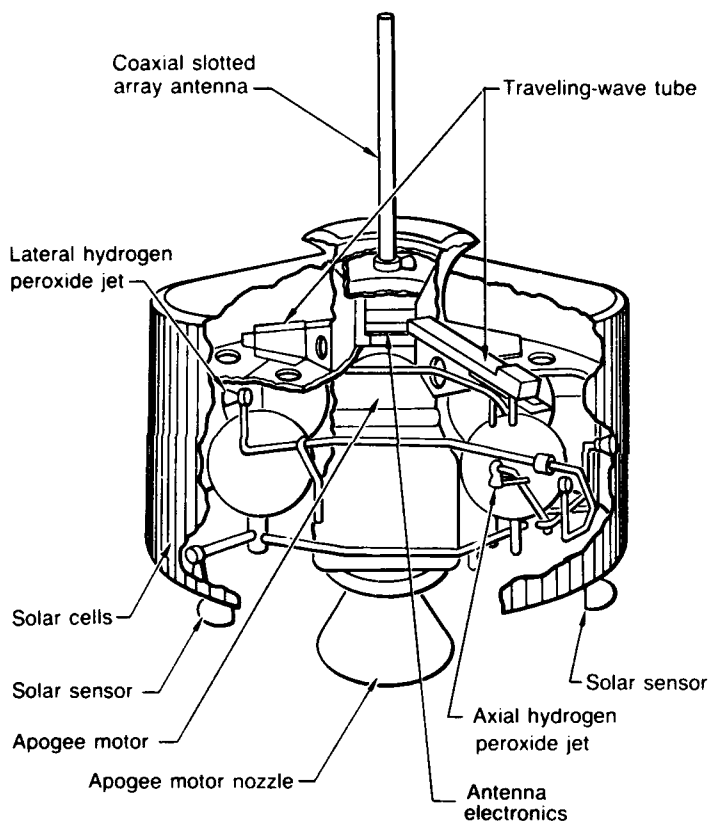
Orbit

1, 2: synchronous altitude, approximately 32-deg inclination

3: synchronous equatorial



Syncom communication subsystem.



Syncom satellite details.

Orbital history

- 1: launched 13 February 1963, all communications failed during orbital insertion
 - 2: launched 26 July 1963, operated through 1966, final turn-off April 1969
 - 3: launched 19 August 1964, operated through 1966, final turn-off April 1969
- Delta launch vehicle

Management

Developed by Hughes Aircraft Company for NASA Goddard Space Flight Center

Syncom 1 was launched in February 1963. The intended orbit was at synchronous altitude with a 33-deg inclination. The satel-

lite operated properly during the ascent, but all communication was lost when the apogee motor fired to inject the satellite into its final orbit. The cause of the failure was the rupturing of a tank of nitrogen that was part of the on-orbit control subsystem. Syncom 2 was successfully launched in July 1963. Like Syncom 1, it was not intended to achieve a stationary synchronous orbit because of the extra propellant weight and control complexity required to attain 0-deg inclination. NASA conducted a number of tests using this satellite, including voice, teletype, and facsimile. During its first year, in addition to engineering tests, 110 public demonstrations were conducted. Their purpose was to acquaint the public with communication satellites and to gain a broader-based, subjective appraisal of system performance.

Syncom 3 was launched in August 1964. By this time, launch vehicle technology had progressed to the point where a true synchronous equatorial (inclination <1 deg) orbit was possible. The only major change in the communication equipment was a channel, with greater bandwidth than Syncom 2, to be used for television transmissions.

The Department of Defense (DoD) also conducted a number of tests using Syncom 2 and 3. During 1965 and 1966, both were used extensively. Five ground stations and one shipborne terminal were in regular system use. Also, tests with aircraft terminals were conducted using the very high frequency (VHF) command and telemetry links. By February 1966, the Syncom 2 and 3 repeaters had a cumulative operational time of 27,000 hr. DoD use of Syncom diminished when the Initial Defense Communication Satellite Program (IDCSP) satellites became operational.

While the Syncom satellites were being developed and tested, an Advanced Syncom study was also being conducted. The Advanced Syncom program was sometimes called Syncom II, which, in some references, is difficult to distinguish from the second satellite of the original Syncom program (Syncom 2 in this report). The conceptual satellite was larger than Syncom, generated more prime power, had higher antenna gain, and had repeaters of two different designs. This program grew beyond an advanced communications experiment and became the Applications Technology Satellite (ATS) program.

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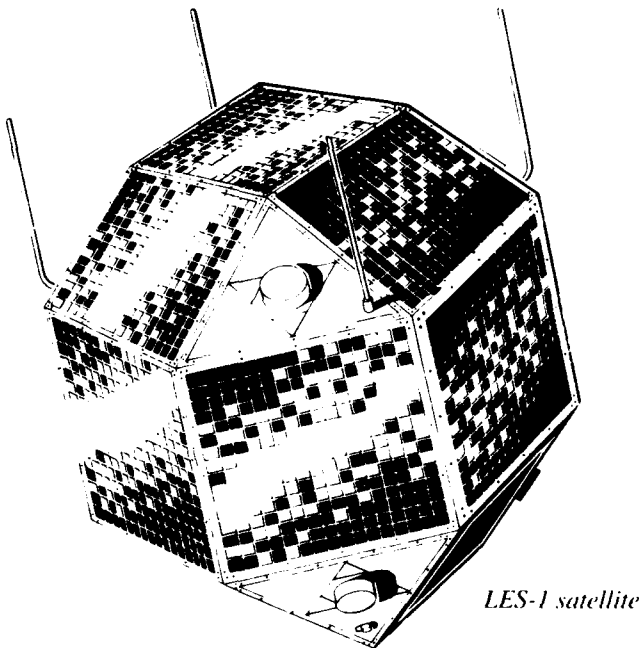
1. *Space Communications and Navigation 1958-1964*, NASA SP-93 (1966).
2. L. Jaffe, "The NASA Communications Satellite Program Results and Status," *Proceedings of the 15th International Astronautical Congress* (1964), Vol. 2: Satellite Systems (1965).

3. C. G. Murphy, "The Hughes Aircraft Company's Syncom Satellite Program," Paper 2619-62, *ARS 17th Annual Meeting and Space Flight Exposition* (November 1962).
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LINCOLN EXPERIMENTAL SATELLITES (LES) -1 to -7



LES-1 satellite

The Massachusetts Institute of Technology (MIT) Lincoln Laboratory has been active for a long time in various aspects of military communications. Early work in ionospheric and tropospheric scatter communications evolved into the West Ford orbital scatter program. At the conclusion of that program in 1963, laboratory efforts were directed toward active communication satellite techniques [1-7]. The large West Ford ground stations were to be used in the new programs. In addition, smaller mobile terminals were to be developed. The basic goals of the program included demonstration of

- High-efficiency, all solid-state transmitters.
- Electronically despun antennas.
- Communications with small mobile terminals.
- Techniques for stationkeeping and attitude control.

Experimental techniques were developed with a view toward eventual application in synchronous altitude military communication satellites.

LES-1 and -2 were essentially identical. They had small polyhedral bodies and were spin-stabilized. The primary experiment was an all solid-state X-band repeater and an eight-horn electronically switched antenna. The other experiments were in attitude sensing and control. The transmitter source was a crystal oscilla-

tor and multiplier chain that was used for upconversion of the signal from intermediate frequency (IF). The X-band power was 200 mW.

The eight horns were mounted so as to provide omnidirectional coverage. Sensors were used to determine the direction of the earth and the satellite spin rate. On-board logic then controlled switches to use the antenna most closely pointed toward the center of the earth. Other details of LES-1 and -2 are as follows:

Satellite

26-sided polyhedron, approximately 24 in. in each dimension
82 lb in orbit

Solar cells, 25 W beginning of life, no batteries

Spin-stabilized with magnetic torquing, 180 rpm

Configuration

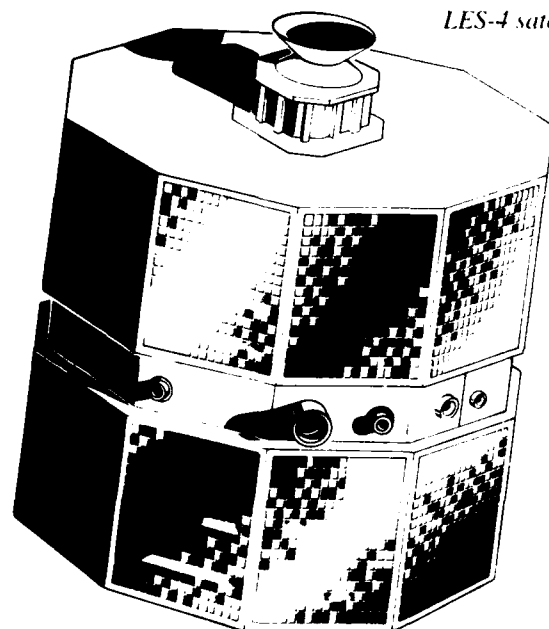
20-MHz bandwidth triple-conversion repeater

Transmitter

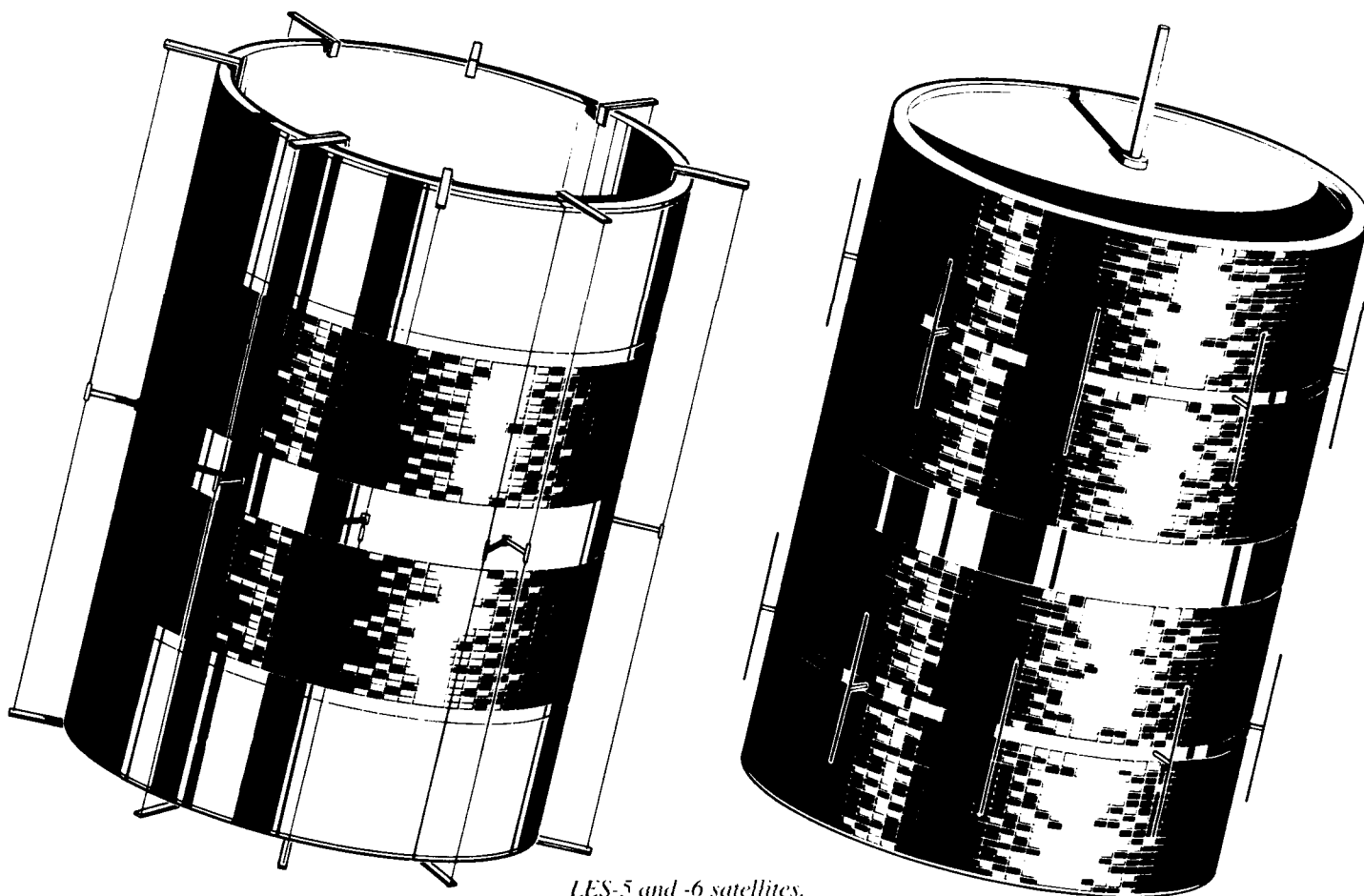
7750 MHz (continuous-wave beacon at 7740 MHz)

All solid state

200-mW output, 115 mW at antenna



LES-4 satellite.



LES-5 and -6 satellites.

Receiver

8350 MHz

16-dB noise figure

G/T: -37 dB/K, maximum

Antenna

Eight horns, electronically switched (only one used at a time)

Approximately 3 dB gain

Design life

Two years

Orbit

1500 × 8000 nmi, 32-deg inclination

Orbital history

1: launched 11 February 1965, launch vehicle failure left satellite in 1500 × 1500-nmi orbit and tumbling

2: launched 6 May 1965, operated until September 1966, final turn-off May 1967

Titan IIIA launch vehicle

Management

Developed by MIT Lincoln Laboratory

LES-1 was launched in February 1965. A launch vehicle failure left the satellite in the wrong orbit. The results of limited tests conducted indicated that the repeater and the switched antennas were operating properly. The satellite then entered a tumbling mode that ended its usefulness. LES-2 was launched in May

1965 and operated as planned until it was turned off in September 1966.

LES-3 was not a communication satellite; its purpose was to transmit an ultrahigh frequency (UHF) signal for propagation measurements. LES-3 is described later. The LES-4 satellite was similar to LES-1 and -2. The interior structure was the same, but the solar array was mounted on a cylindrical shell rather than on a polyhedral shell, the cylindrical array being more efficient for the synchronous equatorial orbit of LES-4. The satellite details are as follows:

Satellite

10-sided cylinder, 31-in. dia., 25-in. height

116 lb in orbit

Solar cells, 36-W initial minimum, no batteries

Spin-stabilized with magnetic torquing, 11 rpm

Configuration

20-MHz bandwidth triple-conversion repeater

Transmitter

7750 MHz (continuous-wave beacon at 7740 MHz)

All solid state

230 mW at antenna, 3-dBW ERP

Receiver

8350 MHz

9-dB noise figure

G/T: -29 dB/K, maximum

Antenna

Transmit: eight horns electronically switched, 10-dB peak gain, circularly polarized, each horn covered about 26×45 deg of a 26×360 -deg toroid

Receive: biconical horn, 26×360 deg, circularly polarized

Design life

Three years

Orbit

Intended: synchronous equatorial

Actual: $105 \times 18,200$ nmi, 26-deg inclination

Orbital history

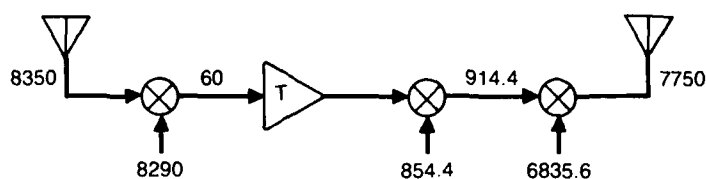
Launched 21 December 1965. Launch vehicle failure resulted in wrong orbit and orientation. By 26 December 1965, the orientation changed enough to permit sufficient solar cell output for operation. Decayed 1 August 1977.

Titan IIC launch vehicle

Management

Developed by MIT Lincoln Laboratory

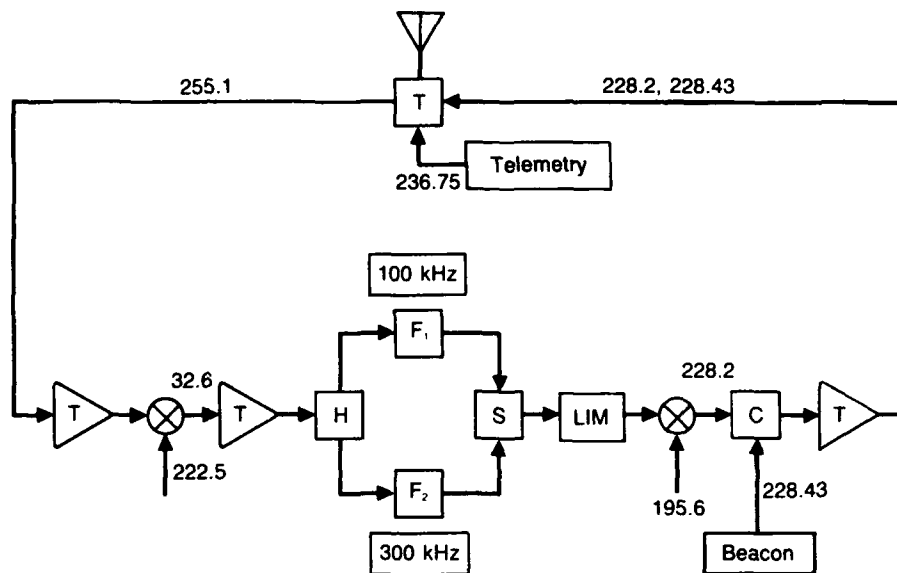
The LES-4 repeater design was nearly the same as the LES-2 design, but improved components significantly lowered the receiver noise figure and increased the transmitter power. The LES-4 transmitting antenna comprised eight horns uniformly spaced in a plane normal to the satellite spin axis. Sun and earth sensors and logic circuits controlled the switches to despin the antenna electronically. The difference in the antenna design from LES-2 was possible because LES-4 was intended for use in a synchronous equatorial orbit, where coverage could be limited to 26 deg in the north-south plane.



LES-1, -2, and -4 communication subsystem.

LES-3 and -4 were launched in December 1965. As the result of a launch vehicle malfunction, the satellites were placed in an elliptical synchronous transfer orbit. Originally, the orientation of LES-4 was such that only enough power was available for operation of the telemetry system. Five days after launch, the spin axis orientation had changed enough so that power was available for the operation of all the satellite systems. From that time, the LES-4 repeater and antenna operated as expected.

The LES-5 and -6 satellites had cylindrical shapes with equipment mounted on a platform near the center of the cylinder and normal to its axis. Both had multiple-element antennas mounted around the cylindrical surface. In addition to their communications equipment, the satellites carried solar cell degradation and radio frequency interference (RFI) experiments. LES-6 also had a prototype autonomous stationkeeping subsystem. The details of LES-5 are as follows:



LES-5 communication subsystem.

Satellite

Cylinder, 48-in. dia., 64-in. height

230 lb in orbit, beginning of life

Solar cells, 136-W initial maximum, no batteries

Spin-stabilized with magnetic torquing, approximately 10 rpm

Configuration

Single 100- or 300-kHz bandwidth double-conversion repeater

Transmitter

228.2 MHz, beacon at 228.43 MHz

Solid state

35-W output, 16.3-dBW ERP beginning of life nominal in satellite's equatorial plane

Receiver

255.1 MHz

3.6-dB noise figure

G/T: -26 dB/K nominal in satellite's equatorial plane

Antenna

Eight dipoles parallel to satellite axis, 2.5-dB gain circularly polarized (electronic despin logic tested on satellite, but not used with antennas)

Design life

Five years

Orbit

$18,000 \times 18,180$ nmi (30-deg drift per day), 7-deg initial inclination

Orbital history

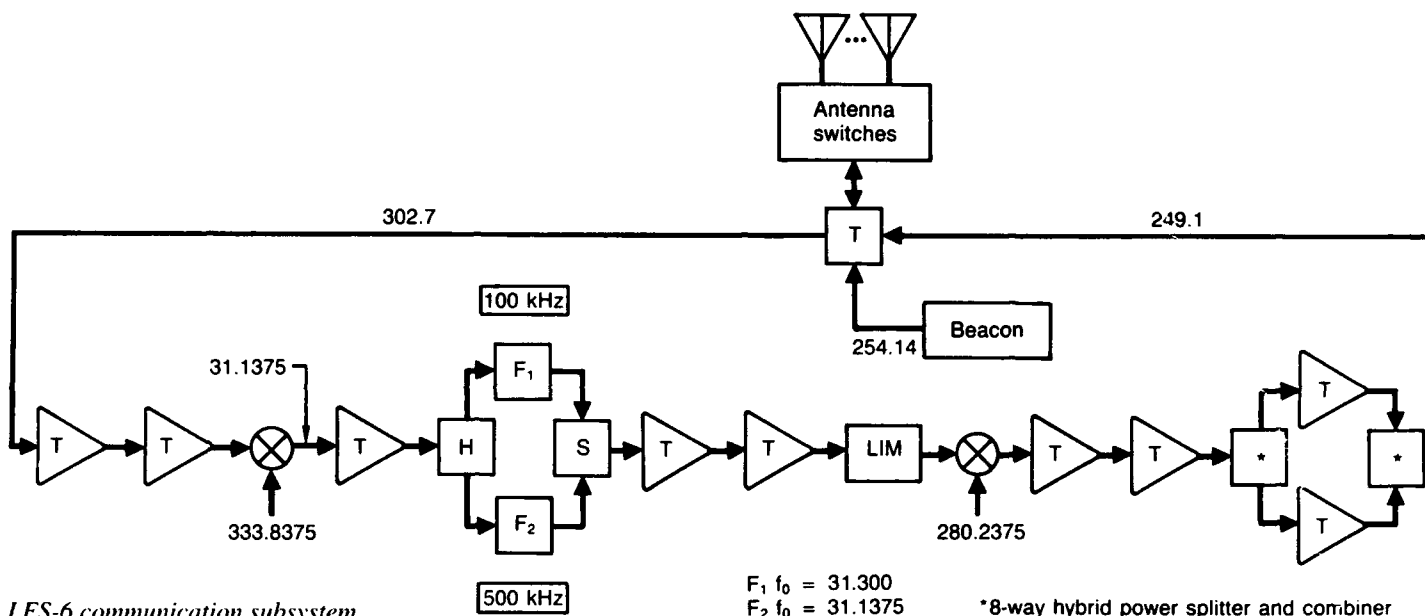
Launched 1 July 1967, operated until May 1971

Titan IIC launch vehicle

Management

Developed by MIT Lincoln Laboratory

The details of LES-6 are as follows:



LES-6 communication subsystem.

Satellite

Cylinder, 48-in. dia., 66-in. height
 398 lb in orbit, beginning of life
 Solar cells, 220-W initial maximum, limited battery capacity
 Spin-stabilized with magnetic torquing, approximately 8 rpm
 Cold gas propulsion for on-orbit use

Configuration

Single 100- or 500-kHz bandwidth double-conversion repeater

Transmitter

249.1 MHz (500-kHz mode), 248.94 MHz (100-kHz mode), beacon at 254.14 MHz

Solid state

Variable output power, 120-W initial nominal (see text)

ERP: 29.5 dBW at beginning of life, 21 dBW after five years

Receiver

302.7 MHz (500-kHz mode), 302.54 MHz (100-kHz mode)

3.6-dB noise figure

Antenna

Sixteen sets of dipoles and cavity-backed slots arranged in eight colinear pairs, circularly polarized

Electronically despun, 9.5-dB gain, 34-deg (north-south) × 54-deg (equatorial plane) beamwidth

Orbit

Synchronous, 3-deg initial inclination

Orbital history

Launched 26 September 1968, operated until turned off in March 1976, still operable in 1978, 1983, and 1988 tests

Titan IIC launch vehicle

Management

Developed by MIT Lincoln Laboratory

LES-5 and -6 had all solid-state communications equipment that operated in the military UHF band. [This is called UHF, al-

though the standard designation is VHF up to 300 MHz and UHF above that.] The LES-5 communication subsystem had a final amplifier of conventional design and had very good efficiency—68% direct current (dc) to radio frequency (RF). The LES-6 amplifier was an experimental design in that it was directly connected to the solar array power bus without any intervening power converters. In this design, all power not required by other satellite systems was directly available to the transmitter, and the transmitter power varied with the available prime power. It was claimed that this design provided an extra 3 dB of transmitted power initially and 0.5 dB extra at the end of satellite life. In-orbit measurements indicated that transmitter power was in the range of 100 to 130 W. LES-5 did not have a despun antenna, but it was used to test some logic that was used in LES-6. The despun circuitry in LES-6 was based on LES-2 and -4 experience and used similar techniques involving earth and sun sensors.

LES-5 was launched in July 1967 with three IDCSP satellites and was placed into a subsynchronous orbit similar to theirs. Both Lincoln Laboratory and the military services conducted a number of tests with LES-5. Aircraft, shipborne, and fixed and mobile ground terminals were all involved in the tests, which were considered very successful. LES-5 operated until May 1971.

LES-6 was launched in September 1968 and was used in tests similar to those conducted with LES-5. The satellite operated satisfactorily. The communication subsystem continued in active use, although by 1975 the effective radiated power (ERP) had decreased 8 dB from its initial value. It was turned off early in 1976 to avoid any frequency conflict with the Marisat launched in February 1976.

The LES-7 satellite was intended to have an all solid state, 100-MHz bandwidth, single-conversion, X-band repeater and a multibeam antenna. Although the program was canceled before the satellite was built, a prototype antenna was built and tested. This antenna was a waveguide lens-type with a cluster of 19 feed horns and was capable of generating beam sizes as small as 3 deg and as large as earth coverage.

* * * * *

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APPLICATIONS TECHNOLOGY SATELLITES (ATS) 1 to 5

The ATS program [1-7] evolved from the Advanced Syncom study. The ATS series continued some of the communications experiments planned for Advanced Syncom and also included meteorological, attitude control and stationkeeping, and space environment experiments. ATS 1 through 5 (called ATS A, B, C, D, and E before launch) constitute the first generation of the program; the second generation is the single ATS 6 satellite. The first objectives of the ATS program were to

- Investigate and flight test technology common to a number of satellite applications.
- Investigate and flight test technology for the geosynchronous orbit.
- Conduct a gravity gradient experiment.

- Conduct flight test experiments for a number of types of satellite applications on each individual spacecraft.

ATS 1 to 5 have some basic similarities, which are summarized in Table 1. The main distinction between the designs of these satellites is that two use spin stabilization and three use gravity-gradient stabilization. Table 1 delineates the communications experiments in each satellite; block diagrams of the equipment associated with each experiment are shown graphically.

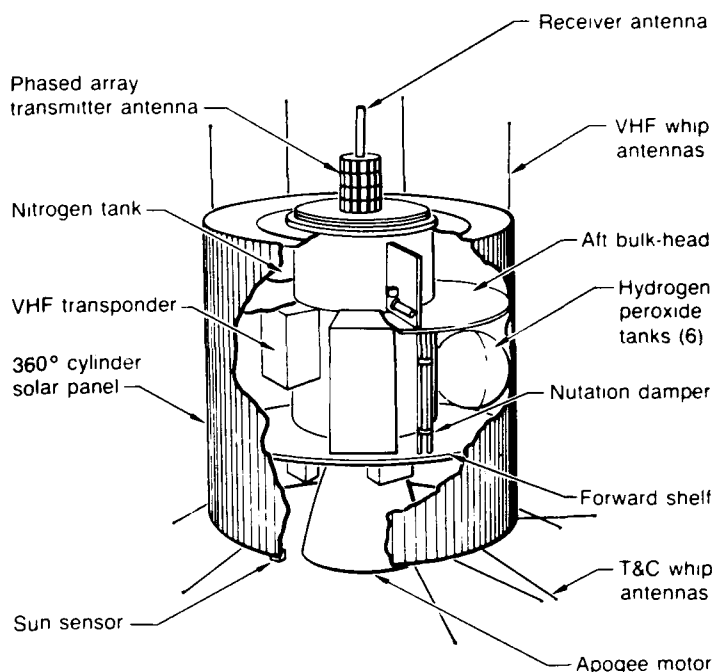
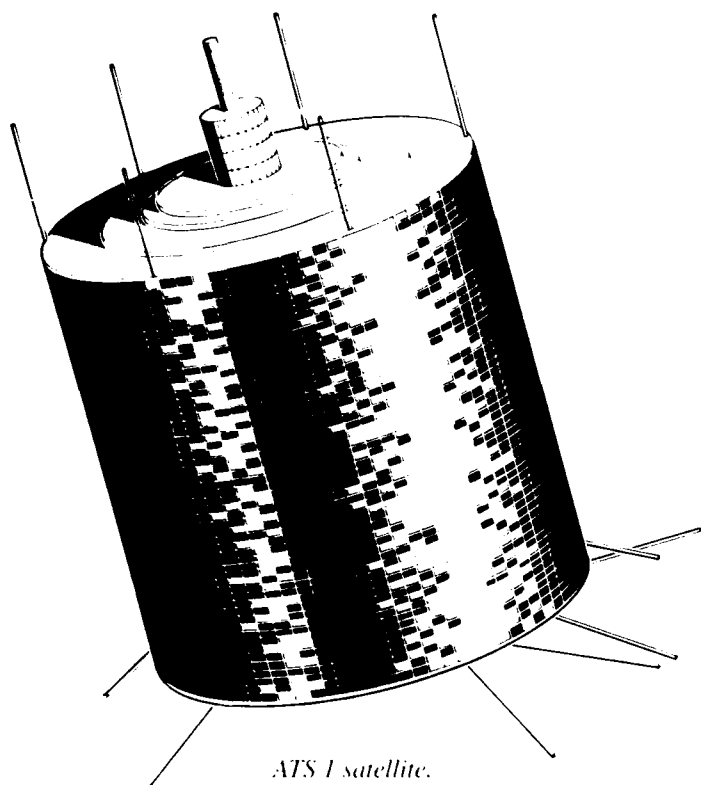
The C-band communications experiment is the only experiment common to all five satellites. The transmit and receive frequencies are in the satellite communication bands used by the Intelsat satellites. Three modes of operation are possible in each of the two repeaters, and the repeaters may operate simultaneously.

Table 1. ATS Characteristics.

CHARACTERISTICS	SATELLITE ^{a, b}				
	ATS 1 (B)	ATS 2 (A)	ATS 3 (C)	ATS 4 (D)	ATS 5 (E)
Cylinder					
Diameter, in.	58	56	58	56	56
Height, in.	54	72	54	72	72
Initial orbital weight, lb	775	702	775	670	670
Solar cells and NiCd batteries, W initial	175	130	175	130	130
Stabilization	Spin	Gravity gradient	Spin	Gravity gradient	Gravity gradient
Design life, yr	3	3	3	3	3
Actual orbit	Synchronous equatorial, 149°W, moved to 164°W in 1982	100 × 600 nmi	Synchronous equatorial, 105°W	130 × 480 nmi	Synchronous equatorial, 70°W
Intended orbit		6000 nmi		Synchronous equatorial	
Launch date	7 Dec 1966	6 Apr 1967	8 Nov 1967	10 Aug 1968	12 Aug 1969
Decay date		2 Sep 1969		17 Oct 1968	
Launch vehicle	Atlas-Agena	Atlas-Agena	Atlas-Agena	Atlas-Centaur	Atlas-Centaur
Experiments					
C-Band communications	Yes	Yes	Yes	Yes	Yes
VHF communications	Yes		Yes		
Millimeter wave propagation					Yes
L-Band communications					Yes

^aAlphabetic designations were used before launch, numeric after.

^bSatellites were developed by Hughes Aircraft Company for NASA, operated by NASA.



The frequency translation mode is used for wideband data relay between two ground stations. In this mode, only one carrier is present, and the signal may occupy the entire 25-MHz repeater bandwidth. Several frequency division multiplexed, single-side-band modulated signals are received in the multiple access mode, and the composite signal is used to phase modulate the transmitter in the satellite. All the ground stations receive the transmitted signal and select the channels of interest from the recovered baseband, which contains all the channels in use. In this way, a number of ground stations can be connected simultaneously. The wideband data mode is used for transmission of information generated by on-board meteorological cameras. Various types of antennas were used on ATS 1 to 5 with the C-band communications experiment. Details of the experiment are as follows:

Configuration

Two 25-MHz bandwidth repeaters

Capacity

1200 one-way voice circuits or one color TV channel

Transmitter

4120- and 4179-MHz

Two TWTs per repeater, used singly or together

4-W output per TWT, except 12 W at 4179 MHz on ATS 3

ERP: 1: 19.5, 22.0 dBW (1, 2 TWTs); 3: 22.0, 25.0 dBW (1, 2 4-W TWTs), 26.5 dBW (1 12-W TWT); 5: 22.5, 25.0 dBW (1, 2 TWTs)

Receiver

6212- and 6301 MHz

Tunnel diode preamplifiers

6.2-dB noise figure

Antenna

1: Transmit: phased array, 16 sets of 4 colinear dipoles, 14-dB gain, 17-deg (north-south) \times 21-deg (equatorial plane) beamwidth. Receive: six-element colinear array, 6-dB gain

2: Horn, 10.5-dB gain

3: Mechanically despun cylindrical reflector with linear feed on cylinder (and spin) axis, 18-dB gain, 17-deg beamwidth

4, 5: Receive: planar array, four slots in each of four waveguide sections, 16.3-dB gain, 23-deg beamwidth

Transmit: similar array, 16.7-dB gain

The VHF experiment, which is on ATS 1 and 3, had the primary objective of evaluating communications between ground stations and aircraft. Other objectives were (1) to demonstrate the collection of meteorological data from remote terminals, (2) to communicate with ships, and (3) to evaluate the feasibility of a VHF navigational satellite. The VHF equipment on the two satellites is similar. The antenna is an eight-element phased array with a receiver and transmitter for each element, but with a common IF amplifier.

It is possible to operate only four transmitters to conserve prime power, or to equalize the phase shifters to generate a toroidal antenna pattern. On ATS 3 only, it is possible to receive a VHF signal and transmit it with the C-band transmitter. Details of the experiment are as follows:

Configuration

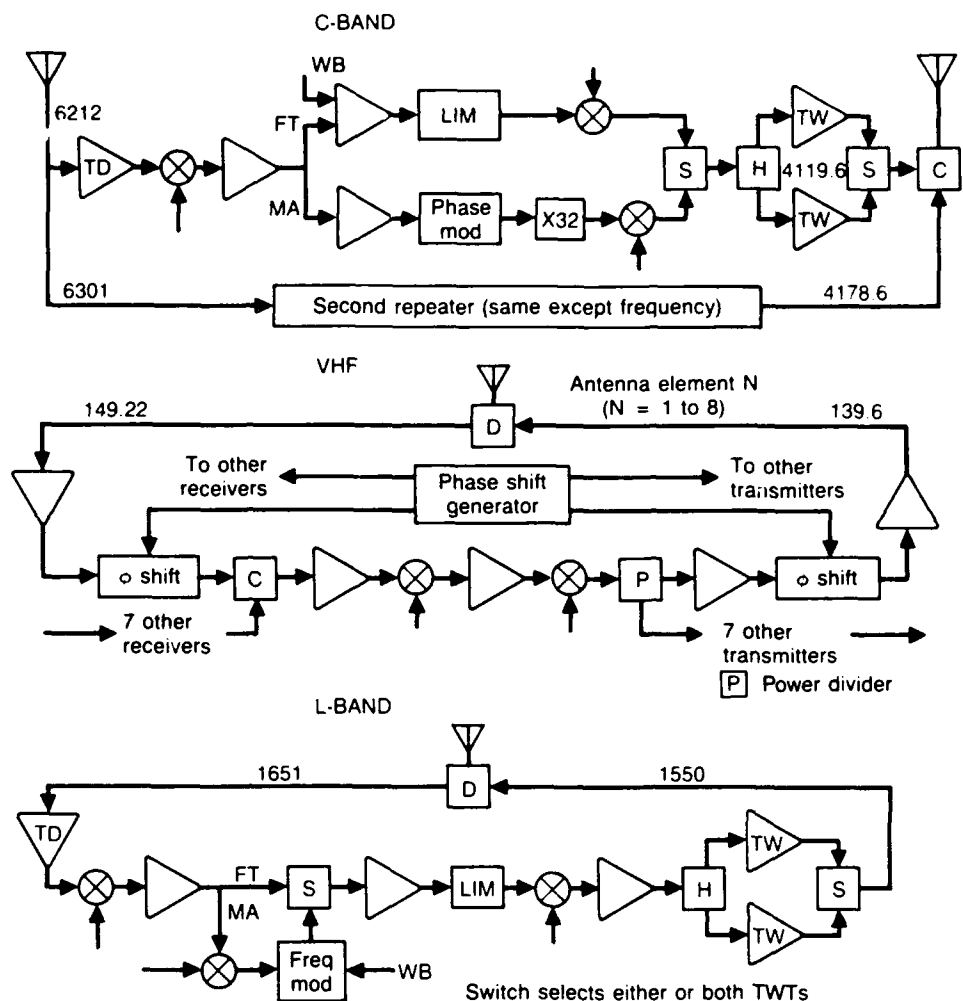
100-kHz bandwidth double-conversion repeater

Transmitter

135.6 MHz

1: 5 W per element, 40 W total, 22.5-dBW ERP

3: 6 25 W per element, 50 W total, 25.2-dBW ERP



ATS communication subsystems.

Receiver

149.2 MHz

1: 4.5-dB noise figure

3: 4.0-dB noise figure

Antenna

Eight-element (dipoles) phased array

1: 9-dB gain

3: 10-dB gain

The millimeter-wave experiment on ATS 5 was designed to measure atmospheric effects on propagation. No repeater was included in the satellite. Rather, on both uplinks and downlinks, a carrier was phase-modulated by a sine wave. The modulation index was selected to equalize power at the carrier and the first two sideband frequencies. Measurements were made at two frequencies, one for the uplink and the other for the downlink. These measurements provided data on absorption, refraction, and fading characteristics. The use of the modulated sidebands provided data on the coherence properties of the atmosphere. Details of the experiment are as follows:

Transmitter

15.3 GHz

Solid state

200-mW output

FT Frequency translation
MA Multiple access
WB Wideband data (onboard data source)

Receiver

31.65 GHz

15-dB noise figure

Antenna

Two horns (one each for transmit and receive)

20-deg beamwidth, 19-dB gain

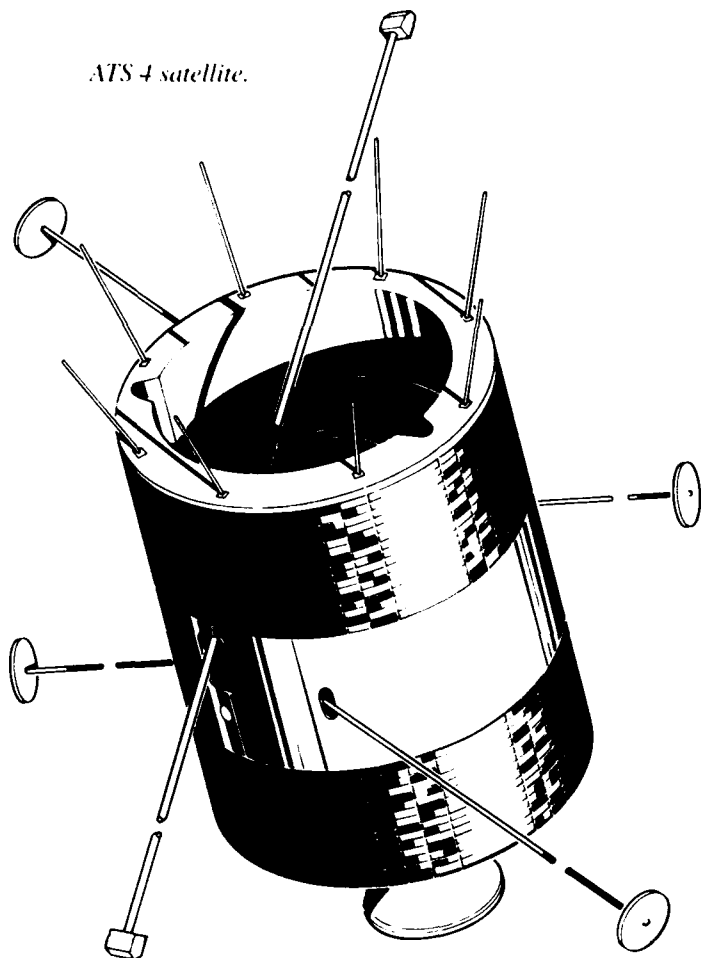
Modulation (uplinks and downlinks)

Phase modulation, 1.43 modulation index to provide approximately equal power in carrier and first sidebands

Modulation frequency: none, 100 kHz, 1 MHz, 10 MHz, or 50 MHz

The L-band (1550/1650-MHz) equipment on ATS 5 has a design similar to the C-band (4/6-GHz) communications equipment on all five ATS satellites. Its purpose is to investigate navigation and traffic control communications for aircraft. For these functions it may be more suitable than VHF, where the available bandwidth is limited and propagation variations limit navigation accuracy. The L-band equipment may be operated as a repeater in the frequency translation mode. In the multiple access mode, as many as 10 single-sideband modulated signals are received at L-band and combined into a composite signal that frequency

ATS 4 satellite.



modulates either the L-band or the C-band transmitter. An alternative frequency translation mode uses the C-band receiver and the L-band transmitter. The transmitter may also be modulated by data from on-board experiments.

Configuration

25-MHz bandwidth repeater

Transmitter

1550-MHz center frequency

Two TWTs used singly or together

12 W per TWT, 22.4-dBW ERP (one TWT), 25.4-dBW ERP (two TWTs)

Receiver

1651-MHz center frequency

8-dB noise figure

Antenna

17.2-dB gain

Of the five ATS launches, three satellites were successfully placed in orbit. ATS 2 and 4 did not achieve the desired orbit because of launch vehicle malfunctions, and few experimental data were obtained. The ATS 2 C-band repeaters operated 12 and 626 hr, and the ATS 4 repeaters operated only 9 and 30 hr. ATS 4 was in orbit only two months. ATS 2 was in orbit over two years but was deactivated after six months.

The experiments on both ATS 1 and ATS 3 were used extensively after the satellites were in orbit. Through March 1971, the four microwave communication repeaters on these satellites had

accumulated about 35,000 hr of use. Tests were run in all modes, and numerous spacecraft parameters were measured. Various tests were run to determine the values of system noise, delay, frequency response, and intermodulation. In general, system performance was satisfactory according to commercial standards. The C-band communications equipment was also used a number of times for international television broadcasts of public interest.

Engineering performance measurements were also performed on the VHF equipment. System performance was evaluated for ground-satellite-aircraft links using equipment installed on several commercial aircraft. The United States Coast Guard performed tests using several shipborne terminals. In general, the results with both aircraft and ships were fair to good communications, and the quality of the satellite link was usually as good as, or better than, alternative communication links. The VHF equipment was also used for experiments in clock synchronization, navigation, and meteorological data collection and dissemination. Results were varied, often limited by available equipment or satellite design, but the experiments did provide a database and recommendations for future work. Since April 1971, the VHF repeater of ATS 1 has been used regularly about 20 hr a week as a single channel international communication system called Project PEACESAT (Pan Pacific Education and Communication Experiments by Satellite). PEACESAT provides cultural and emergency communications to about 20 nations (mostly small island nations) of the Pacific basin. ATS 3 is also providing communication services in the Pacific basin. Both ATS 1 and ATS 3 have degraded in performance, but both continued in use of more than six times their three-year design lives. In 1985, ATS 1 failed to respond to commands; therefore, it can no longer be kept at the correct location to serve all the Pacific basin users, even though its electronics remain useable. ATS 3 was still functioning properly into 1986.

ATS 5 was successfully placed into synchronous orbit. The satellite was to be spinning upon orbital injection and then despun, at which time the gravity-gradient stabilization would begin. During orbital injection, however, the satellite developed a spin about an axis normal to the intended spin axis. In this orientation, the satellite could not be despun. Because of the spinning condition, the satellite antennas pointed toward the earth only a small portion of each revolution. Hence, the communication experiments were operated with limited success in a pulsed type of operation synchronized with the periods of correct antenna orientation.

* * * * *

1. *Technical Data Report for the Applications Technology Satellite Program*, Goddard Space Flight Center (3 March 1967; revised periodically until 20 April 1971), six volumes.
2. R. H. Pickard, "The Applications Technology Satellite," *Proceedings of the 16th International Astronautical Congress* (1965), Vol. 4: *Meteorological and Communication Satellites* (1966).
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4. *Satellite Communications* (January 1982), p. 22; (November 1985), p. 45.
5. *NASA Semiannual Reports to Congress*, Vols. 16 (July-December 1966), 21 (January-June 1969).
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APPLICATIONS TECHNOLOGY SATELLITE (ATS) 6

The ATS 6 satellite [1-26] was the second generation of the NASA Applications Technology Satellite program. Prior to launch, the satellite was designated ATS F. The program had included a second, very similar satellite called ATS G, but it was canceled for budgetary reasons. ATS 1 to 5, launched in 1966 through 1969, constituted the first generation. Eight of the experiments on ATS 6 were for communications and propagation studies that covered a frequency range from 860 MHz to 30 GHz.

ATS 6 consisted of a 30-ft diameter parabolic antenna, an earth-viewing module located at the focus of the parabola, two solar arrays, and the interconnecting structures. The antenna and the solar arrays were deployed after the satellite was in orbit. All the communications experiments were located in a section of the earth-viewing module. Feed horns for the large parabola were mounted on top of the module and other antennas on the bottom. General satellite characteristics are as follows:

Shape, size

30-ft dia. parabolic reflector, 6.5-ft dia. hub section with copper-coated dacron mesh supported by 48 aluminum ribs

Earth-viewing module at antenna focus with experiment sections and support subsystems, 54 × 54 × 65 in.

Two solar arrays (deployed in space), each half a cylinder, 54-in. radius, 94 in. long

Maximum height, 27 ft, 6 in.

Maximum span, 51 ft, 8 in.

Initial orbital weight

2970 lb

Power

Solar cells and NiCd batteries

645-W initial maximum

415-W minimum after five years

Stabilization

Three-axis-stabilized with inertia wheels.

0.1-deg pointing accuracy

Pointing to any location on earth

Tracking of low-altitude satellite over ± 11 deg from local vertical

Design life

Two years (required), five years (goal)

Orbit

Synchronous equatorial; 94° W longitude until June 1975, 35° E longitude from July 1975 to July 1976, 140° W longitude until July 1979; moved out of synchronous orbit late 1979 or early 1980

Orbital history

Launched 30 May 1974

Titan IIC launch vehicle

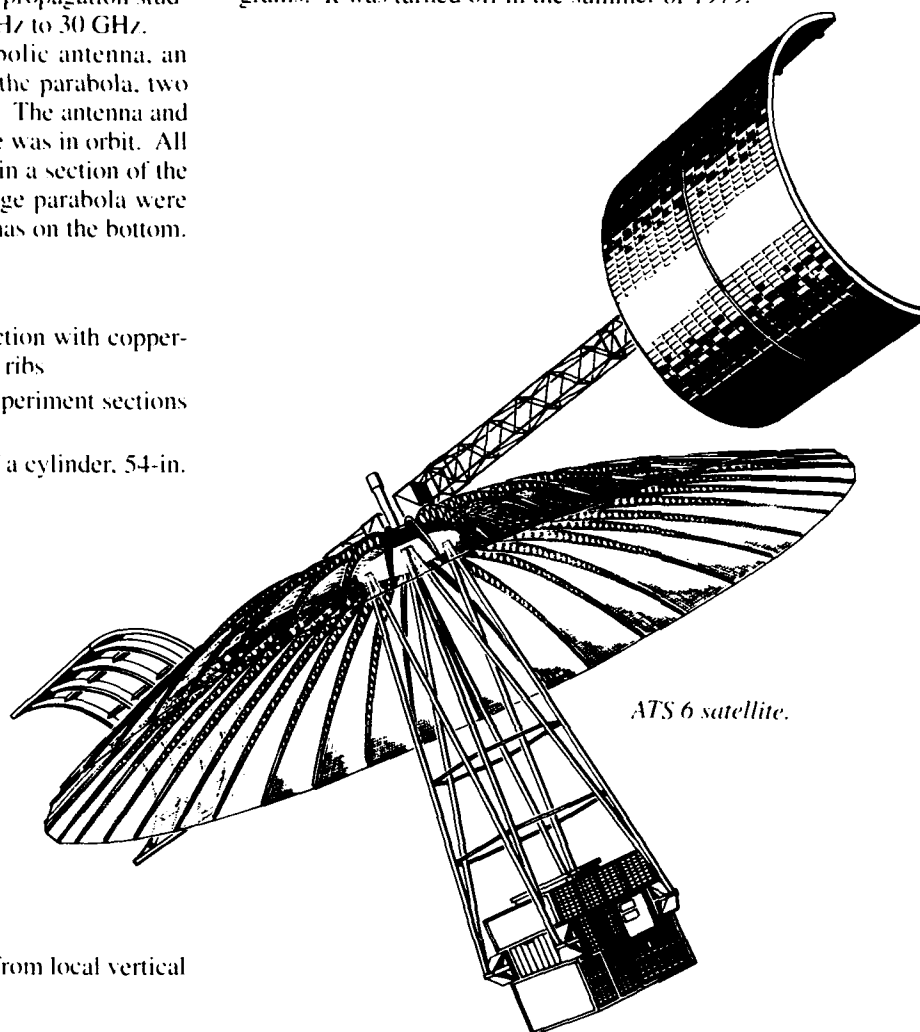
In use until turned off (July 1979)

Management

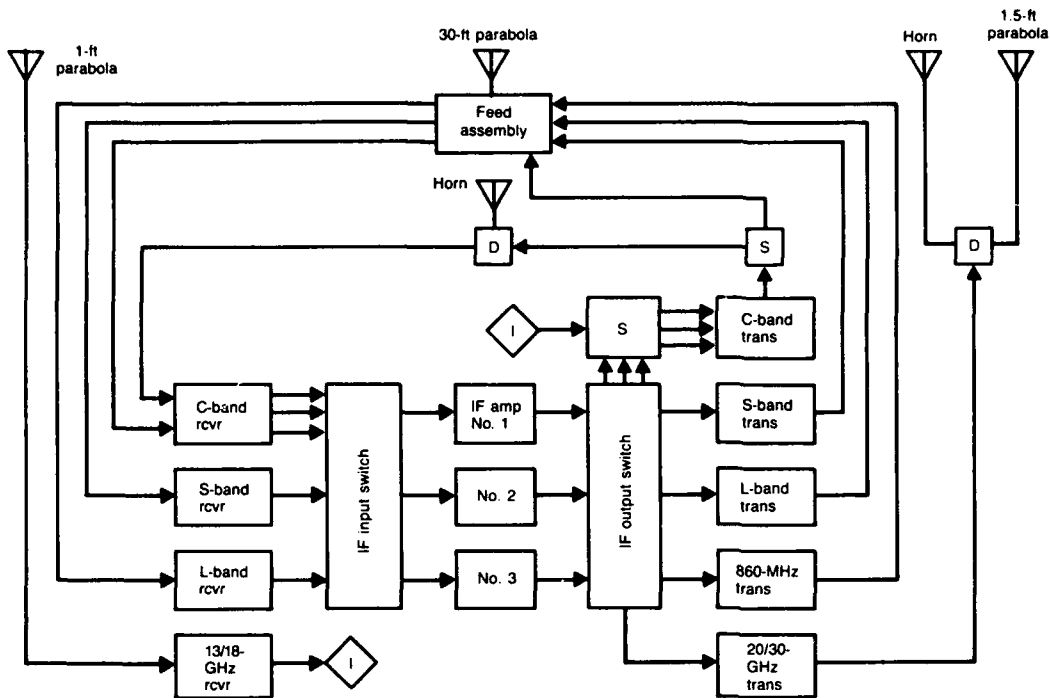
Developed by Fairchild for NASA

ATS 6 was launched in May 1974. It was originally positioned at 94° W longitude, where it was used with United States ground stations for one year. During June 1975, it was moved to 35° E longitude for the instructional television experiment broadcasts to India. At the same time, the NASA millimeter-wave experiment

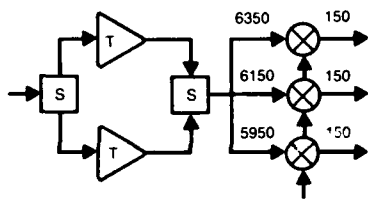
was used in conjunction with several European ground terminals. After the one-year Indian experiment, in the fall of 1976, the satellite was slowly returned to the Western Hemisphere. During the transfer period, demonstrations of the social benefits possible with such a satellite were made in 27 countries. ATS 6 was then located at 140° W longitude and used in several experimental programs. It was turned off in the summer of 1979.



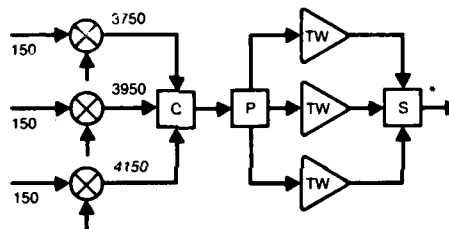
The position location and aircraft communication experiment (PLACE) was an extension of similar experiments conducted at ATS 1, 3, and 5. Like ATS 5, ATS 6 used frequencies near 1550 and 1650 MHz (L-band) for transmissions to and from aircraft. Both voice and digital data transmissions and a four-tone ranging system for aircraft position determination were part of the experimental program. The system was configured to permit multiple access voice from 100 aircraft in 10-kHz channels. At first, three ground terminals were used to simulate aircraft, with later experiments involving actual aircraft. The ranging signal operation had a transmission to all aircraft, with a coded data channel to designate one aircraft at a time to return the signal. All frequencies were coherently related to the ground station transmitter frequency so that range rate as well as range could be determined. Experiments included multiple aircraft tracking, determination of capacity limitations (ground equipment simulated most of the aircraft), determination of multipath effects, and evaluation of ground and aircraft terminals. Details of the experiment are as follows:



ATS 6 communication subsystem.

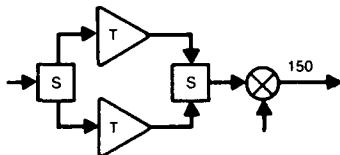


C-BAND RECEIVER

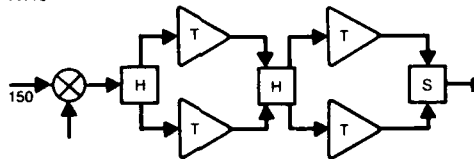


C-BAND TRANSMITTER

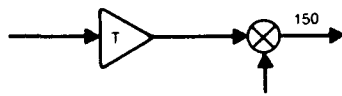
* Switch selects any 1 or 2 TWTs



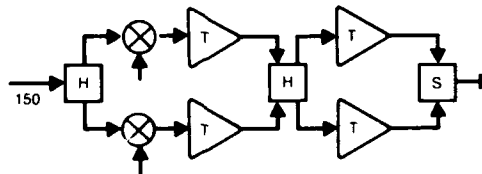
S-BAND RECEIVER



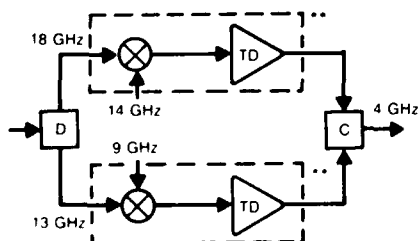
S-BAND TRANSMITTER
(L-band is identical)



L-BAND RECEIVER

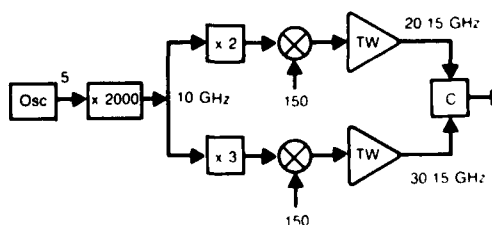


860-MHz TRANSMITTER



13/18-GHz RECEIVER

Redundant units not shown



20/30-GHz TRANSMITTER

Configuration

Two-way link through ATS 6 between a ground terminal and aircraft for both voice and ranging functions

Transmitter (ATS 6 to aircraft link)

1550 MHz

40-W output, 40.3- or 51.0-dBW ERP

Receiver (aircraft to ATS 6 link)

1650 MHz

G/T: -4.4 or +5.5 dB/K

Antenna

30-ft parabola, 28- to 29-dB gain with 0.8- × 7.5-deg fan beam, 38.5-dB gain with 1.5-deg pencil beam, circular polarization

Transmitter (ATS 6 to ground link)

One of 3750, 3950, or 4150 MHz

12-W output, 28-dBW ERP on axis

Receiver (ground to ATS 6 link)

One of 5950, 6150, or 6350 MHz

G/T: -17 dB/K peak

Antenna

Horn, 16.3- to 16.5-dB gain, 13- × 20-deg beamwidth, linear polarization

The satellite instructional television experiment (SITE, or sometimes ITV) was a cooperative effort by NASA and the government of India. The basic objectives were to demonstrate the use of satellite television broadcasting for instructional purposes and to evaluate the various techniques and equipment. The television programs were prepared by the Indian government and transmitted at 6 GHz to ATS 6 from one of three ground stations in India. The satellite retransmitted the signals at 860 MHz. The 860-MHz signal was directly received in 2000 villages by community television receivers with simple 10-ft parabolic antennas. The signal was also received by regular television stations and re-broadcast to about 3000 villages in the standard VHF television band. The television signal had two audio channels with different dialects. (Operational systems may have as many as 14 audio channels to cover the major dialects and languages used in India.) The one year of SITE operation provided experience for development of a national television broadcast satellite system being planned by India. Details of the experiment are as follows:

Configuration

40-MHz bandwidth double-conversion repeater

Transmitter

860 MHz (3750 MHz used occasionally to monitor signals)

80-W output, 51.0-dBW ERP peak

Receiver

5950 MHz

G/T: -17 dB/K peak

Antenna

Transmit: 30-ft parabola, 33-dB peak gain, 2.8-deg beamwidth, circular polarization

Receive: horn, 16.3-dB peak gain, 13- × 20-deg field of view, linear polarization (30-ft parabola might be used for receiving in-

stead of horn, 48.4-dB peak gain, 0.4-deg beamwidth, +13.7 dB/K G/T)

The TRUST experiment (television relay using small terminals) was similar to SITE and used the same equipment in ATS 6. SITE was used in a year-long instructional program with evaluations of that program, whereas the main objectives of TRUST were hardware oriented. System performance was compared with design values, and ionospheric effects on system performance were measured. Considerable emphasis was placed on the small 860-MHz receiver. A program goal was to develop a terminal that would cost less than \$200 in large-volume production. The experiment details are the same as given for SITE.

The health/education experiment (formerly the educational-television experiment) was used to test satellite distribution of educational and medical programs. The educational programs were primarily for children, and the medical programs covered both professional education and consultation and general health care. The receiving terminals for the experiment were in areas where present television services are limited because of either geographical (Rocky Mountain states, Alaska) or social (Appalachia) factors. Two separate television channels could have been transmitted by ATS 6 using separate antenna beams (produced by two feed horns and the 30-ft reflector). Since a 1-deg beamwidth was used, transmission to the various geographic areas occurred at different times. The transmissions from ATS 6 were at 2570 and 2670 MHz (S-band). Some of the receiving terminals were equipped to provide an S-band return link through ATS 6. Details of the experiment are as follows:

Configuration

Forward link: two 30- to 40-MHz bandwidth repeaters for two FM-TV carriers with sound subcarriers plus separate telephone carriers

Return link: for telephone carriers

Transmitter

2570 and 2670 MHz (also C-band for monitoring)

15-W output, 53.0-dBW peak ERP

Receiver

5950 MHz

G/T: -17 dB/K peak

Antenna

Transmit: 30-ft parabola, 41.5-dB peak gain, 1-deg beamwidth, circular polarization

Receive: horn, 16.3-dB peak gain, 13- × 20-deg field of view, linear polarization (30-ft parabola might be used for receiving instead of horn, 48.4-dB peak gain, 0.4-deg bandwidth, 13.7 dB/K G/T)

In the tracking and data relay satellite experiment, ATS 6 was used to relay commands and tracking signals to, and data and tracking signals from, GEOS-3 and Nimbus 6. The returned data were compared with data received from the spacecraft at a standard ground terminal. The orbit was computed from the range and range rate data obtained through ATS 6 and the uncertainty of the orbit determination compared with theoretical predictions. ATS 6 used S-band for communications with the spacecraft and C-band for communications with the ground. An array of feed horns under the 30-ft reflector was switched to allow the antenna beam to track the spacecraft along its orbit. The same equipment was also used to provide a communications relay between the

ground and an Apollo spacecraft during the Apollo-Soyuz Test Project. Details of the experiment are as follows:

Configuration

Two 12- or 40-MHz bandwidth channels

Two-way link through ATS 6 between ground and a low-altitude satellite

Transmitter (ATS 6 to satellite link)

2063 MHz

20-W output, 48.0-dBW ERP minimum

Receiver (satellite to ATS 6 link)

2253 MHz

G/T: 7.0 dB/K minimum

Antenna

30-ft parabola, 36.4-dB gain minimum, 13.2-deg overall field of view using switched feeds, circular polarization

Transmitter (ATS 6 to ground link)

3753 MHz primary (alternates 3953 or 4153 MHz)

12-W output, 28.0-dBW ERP peak

Receiver (ground to ATS 6 link)

5938 MHz primary (alternates 6138 or 6338 MHz)

G/T: -17 dB/K peak

Antenna

Horn: 16.5-dB transmit gain (peak), 16.3-dB receive, 13- × 20-deg field of view, linear polarization

The frequencies from 5925 to 6425 MHz are shared by terrestrial and satellite communication services. The RFI experiment was used to determine the extent of interference between these two services. When the RFI experiment was operating, the entire 500-MHz bandwidth of interest was received by ATS 6 and retransmitted to a ground station. Data processing at the ground station was used to determine the power levels and geographic and frequency distribution of the terrestrial sources of noise. The minimum detectable noise source ERP was 10 dBW, and the frequency resolution was 10 kHz. A portable ground station was used as a tracking beacon for ATS 6 and as a system calibration source. Details of the experiment are as follows:

Receiver

5925 to 6425 MHz

G/T: +17.0 dB/K (30-ft parabola) or -17.0 dB/K (horn) peak, minimum detectable ground source is 10-dBW ERP

Antenna

30-ft parabola, 48.4-dB gain peak, 0.4-deg beamwidth, circular or linear polarization

Horn, 16.3-dB gain peak, 13- × 20-deg beamwidth, linear polarization

ATS 6 had two millimeter-wave experiments. The NASA experiment used a C-band uplink and 20- and 30-GHz downlinks, whereas the Communications Satellite (Comsat) Corporation experiment used 13- and 18-GHz uplinks and a C-band downlink. In the NASA experiment, the 20- and 30-GHz downlinks could have been unmodulated, modulated by an on-board tone generator, or modulated by a communication signal received on the C-band uplink. The continuous-wave propagation tests had suffi-

cient power to accommodate fades as deep as 60 dB, whereas the communication mode was used with digital data rates up to 40 Mbps. A 4-GHz downlink was used with the millimeter-wave downlinks for comparisons. The objectives of the experiment were to measure the characteristics of the millimeter-wave links and to compare directly measured propagation effects with indirect measurements such as radiometric sky temperature, radar backscatter, and meteorological conditions. Details of the experiment are as follows:

Configuration

Propagation modes: continuous-wave or multitone downlinks

Communications mode: 40-MHz bandwidth repeater

Transmitter (propagation modes)

20.0 and 30.0 GHz

Continuous wave: 2-W output, 30-dBW peak ERP

Multitone (nine tones): 0.06-W output/tone, 15-dBW peak ERP/tone

Transmitter (communications mode)

20.15 and 30.15 GHz and one of 3750, 3950, or 4150 MHz

20.15 GHz: 2-W output, 40-dBW peak ERP

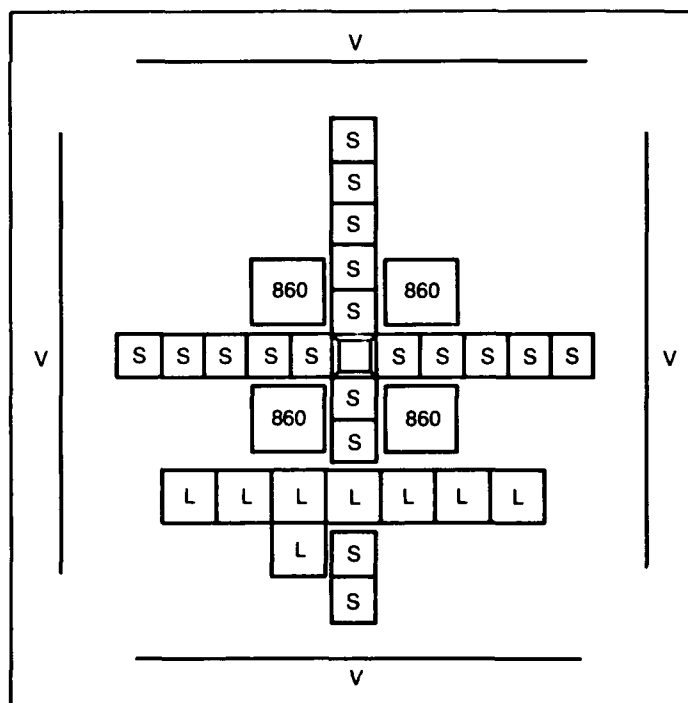
30.15 GHz: 2-W output, 42-dBW peak ERP

C-band: 12-W output, 28-dBW peak ERP

Receiver (communications mode only)

One of 5950, 6150, or 6350 MHz

G/T: 13.7 dB/K (30-ft parabola), -17 dB/K (horn)



Center	C-band horn surrounded by 4-horn S-band monopulse
S	S-band cavity backed crossed dipoles
L	L-band cavity backed crossed dipoles
860	860-MHz cavity backed crossed dipoles
V	VHF (130 to 150 MHz) dipoles

Feed structure for the ATS 6 30-ft reflector.

Antenna

Propagation mode: horn, 27-dB peak gain, 5- × 7-deg beamwidth, linear polarization

Communication mode:

20.15 GHz: 1.5-ft parabola, 37-dB gain, 2.4-deg beamwidth

30.15 GHz: 1.5-ft parabola, 39-dB gain, 1.6-deg beamwidth

C-band transmit: horn, 16.5-dB gain, 13- × 20-deg beamwidth

C-band receive: horn, 16.3-dB gain, 13- × 20-deg beamwidth or 30-ft parabola, 48.4-dB gain, 0.4-deg beamwidth

In the Comsat Corporation millimeter-wave experiment, 39 unmodulated uplinks were received by ATS 6 and retransmitted to a ground station on a C-band downlink. Fifteen stations scattered throughout the eastern part of the United States (>100 miles separation) each transmitted 13- and 18-GHz uplinks. Nine additional stations transmitting 18-GHz uplinks were placed in groups of three near (<25 miles separation) three dual-frequency stations. The experiment operated on a nearly continuous basis for about one year. The results are useful for determining the required weather margins for future communication links using frequencies near 13 or 18 GHz. Data from the three groups of stations, with smaller separations, can be used to determine attenuation correlation and, hence, the uplink improvement possible with space diversity. Details of the experiment are as follows:

Configuration

Thirty-nine unmodulated uplink carriers received and retransmitted to a control ground terminal in a 30-MHz bandwidth

Transmitter

4150 MHz

0.2- to 1.3-mW output per carrier

-13- to -21-dBW ERP per carrier

Receiver

Fifteen carriers near 13.19 GHz and 24 near 17.79 GHz

10-dB noise figure

Antenna

Transmit: horn, 17-dB gain

Receive: 1-ft parabola, 26/28-dB peak gain (13/18 GHz), 4- × 8-deg beamwidth, linear polarization

The communications equipment on ATS 6 included four receivers (C-, S-, L-band, and 13/18 GHz), three IF amplifiers, and five transmitters (C-, S-, L-band, 860 MHz, and 20/30 GHz). The 13/18-GHz uplink was downconverted to C-band, amplified, and routed to the C-band transmitter. The other uplinks were amplified and filtered before downconversion to the 150-MHz intermediate frequency. Any receiver (except 13/18 GHz) could have been connected to any one of the three identical IF amplifiers, which could have provided either 12- or 40-MHz bandwidths. The IF outputs could have been connected to any of the transmitters. The transmitters included upconverters, driver amplifiers, and power amplifiers; most of these elements were redundant. The C-band and 20/30 GHz transmitters used traveling wave tubes (TWTs), whereas the lower-frequency transmitters were all transistorized. The primary communication antenna was the 30-ft parabola. In addition, the satellite had a C-band horn and two small parabolas and a horn for the millimeter-wave experiments. The feed structure for the large reflector included 36 elements to provide efficient performance for the various frequencies and beam patterns used in the communications experiments. The ar-

range of the feed elements on the top surface of the earth-viewing module is shown.

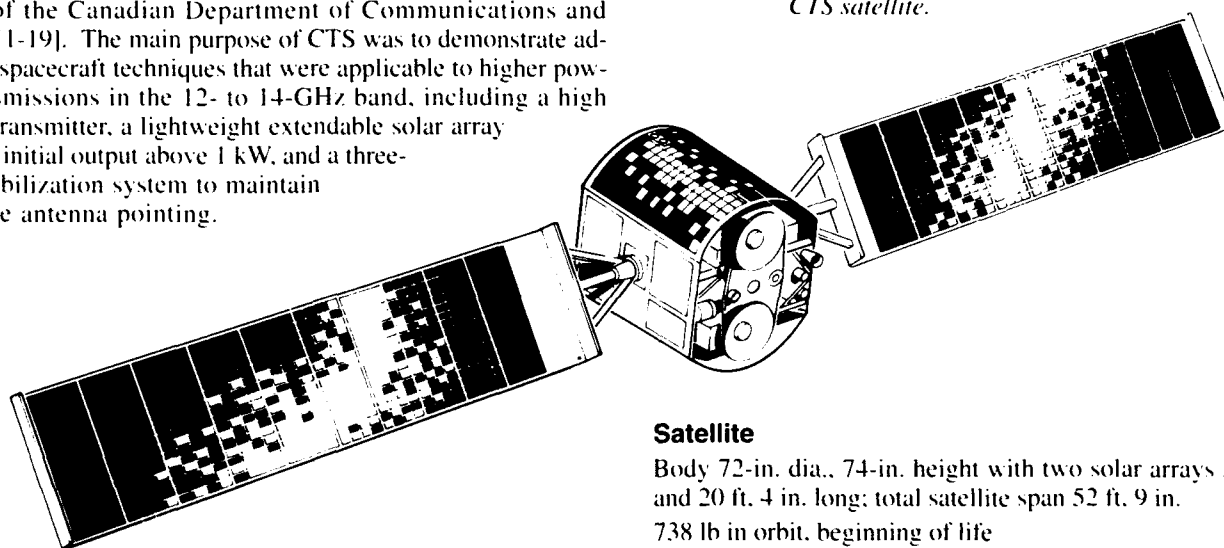
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 - b. R. B. Marsten, "ATS-6—Significance."
 - c. W. N. Redisch, "ATS-6—Description and Performance."
 - d. J. P. Corrigan, "ATS-6—Experiment Summary."
 - e. J. L. Boor, "ATS-6—Technical Aspects of the Health/Education Telecommunications Experiment."
 - f. J. E. Miller, "ATS-6—Satellite Instructional Television Experiment."
 - g. J. E. Miller, "ATS-6—Television Relay Using Small Terminals Experiment."
 - h. P. E. Schmid, B. J. Trudell, and F. O. Vonbun, "ATS-6—Satellite to Satellite Tracking and Data Relay Experiments."
 - i. V. F. Henry, "ATS-6—Radio Frequency Interference Measurement Experiment."
 - j. L. J. Ippolito, "ATS-6—Millimeter Wave Propagation and Communications Experiments at 20 and 30 GHz."
 - k. G. Hyde, "ATS-6—Preliminary Results from the 13/18 GHz COMSAT Propagation Experiment."
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COMMUNICATIONS TECHNOLOGY SATELLITE (CTS)

The Communications Technology Satellite (CTS), formerly called Cooperative Applications Satellite C (CAS-C), was a joint effort of the Canadian Department of Communications and NASA [1-19]. The main purpose of CTS was to demonstrate advanced spacecraft techniques that were applicable to higher power transmissions in the 12- to 14-GHz band, including a high power transmitter, a lightweight extendable solar array with an initial output above 1 kW, and a three-axis stabilization system to maintain accurate antenna pointing.



CTS satellite.

Canada developed the satellite. NASA provided the primary experiment, which was a 200-W output, 50% efficient 12-GHz TWT. NASA also had the responsibility for launching the satellite. The European Space Research Organization (ESRO), now known as ESA (European Space Agency), participated in the CTS program by supplying one of the TWTs, a parametric amplifier, and some other items.

The satellite body was roughly a cylinder 6 ft in height and diameter, which was injected into a synchronous equatorial orbit in a spinning condition. After it was despun, two 51- × 244-in. solar panels were deployed from opposite sides of the body. The solar panels rotated about their long axis to track the sun continually. The antennas were mounted on gimbals on the front (earth-viewing) end of the body and required no deployment. Satellite details are as follows:

Satellite

Body 72-in. dia., 74-in. height with two solar arrays 51 in. wide and 20 ft. 4 in. long; total satellite span 52 ft. 9 in.

738 lb in orbit, beginning of life

Sun tracking solar array and NiCd batteries, 1360 W initially, approximately 930 W minimum during last year (1979)

Three-axis stabilization using a variable speed momentum wheel, ± 0.1 deg about pitch (north-south) and roll (velocity vector) axes, ± 1.1 deg about yaw (radial) axis

Solid rocket motor for apogee maneuver, hydrazine thrusters for on-orbit use

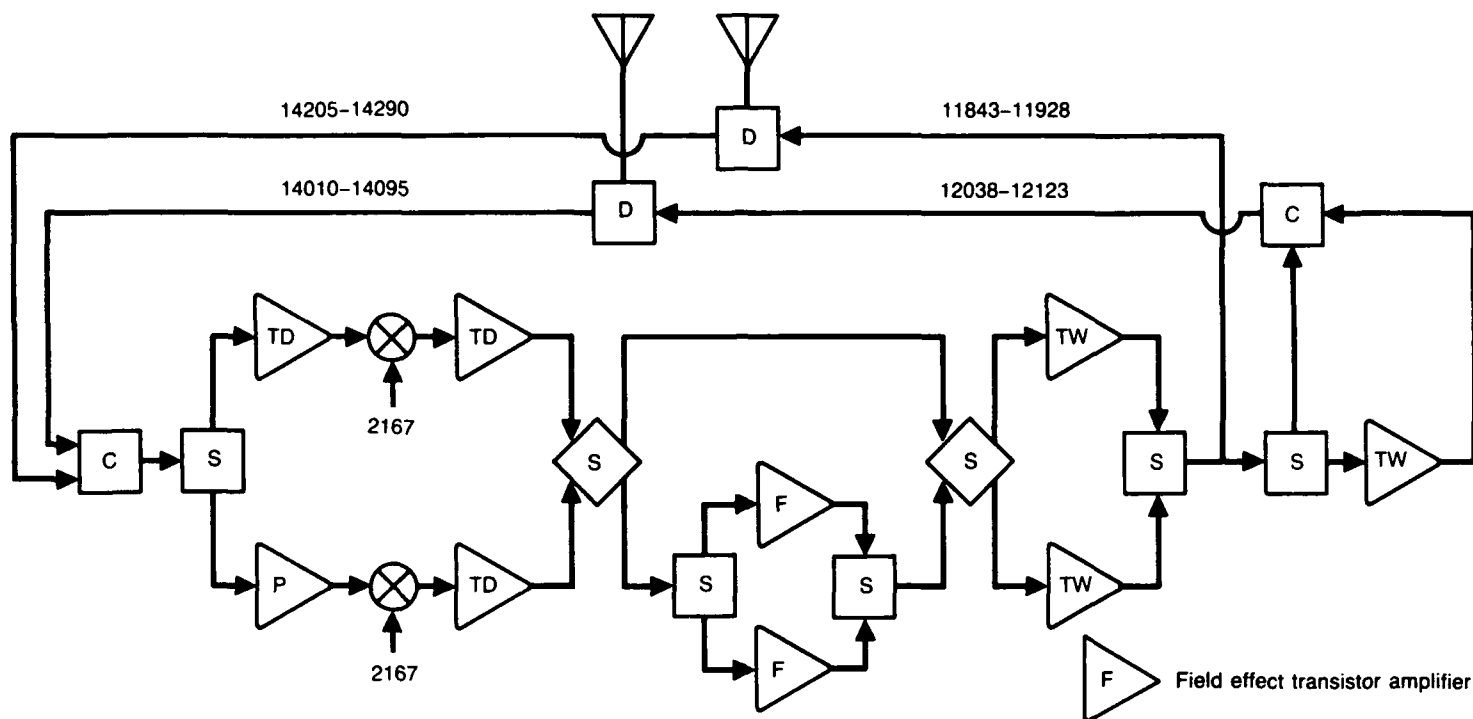
Configuration

Two 85-MHz bandwidth single-conversion repeaters

Transmitter

11.843 to 11.928 GHz and 12.038 to 12.123 GHz

Normal configuration 20-W TWT on low band and 200-W TWT on high band, alternately both bands share the 20-W TWT (at reduced capability)



CTS communication subsystem.

Receiver

14,010 to 14,095 GHz and 14,205 to 14,290 GHz

Two preamplifier chains (one on, one standby)

Noise temperature:

Approximately 2000 K with tunnel diode preamplifier

Approximately 1350 K with parametric amplifier

G/T: 6.4 dB/K on-axis with parametric amplifier

Antennas

Two 28-in. dia. antennas, 36.2-dB gain on axis for transmit and receive, 2.5-deg beamwidth, steerable over ± 7.25 deg, linear polarization

Design life

Two years

Orbit

Synchronous equatorial, 116°W longitude, (142°W last half of 1979) $\pm 0.2^\circ$ E-W stationkeeping, inclination ≤ 0.8 deg through mid 1979

Orbital history

Launched 17 January 1976

Delta 2914 launch vehicle

In use until turned off (November 1979)

Management

Developed by Canadian Department of Communications

The communication equipment included 20- and 200-W TWTs. Two 85-MHz channels were available. Normally, one of the redundant 20-W TWTs was the power amplifier for one

Table 1. CTS Ground Terminals.

FUNCTION	DIAMETER, ft	ANTENNA		RECEIVER TYPE AND NOISE TEMPERATURE, K	GT, db/K	MAXIMUM TRANSMITTER POWER, W
		PEAK GAIN, dB	BEAMWIDTH, deg			
Control terminal						
Transmit and receive TV and multiplexed voice signals	30	59	0.18	Uncooled paramp, 425	32.9	1000
Remote terminals						
TV transmission	10	50	0.54	TDA, 1150	19.5	1000
TV reception and two-way voice	8	48	0.67	TDA, 1150	16.5	1
Two-way voice	4	42	1.3	Mixer, 2660	7.8	1
Recieve FM sound broadcast	2 equivalent	35	2 x 4	Mixer, 2660	0.8	

channel as well as the low-level driver for the 200-W TWT on the second channel. In a backup mode, the 200-W TWT was bypassed and the output of the 20-W TWT was divided between the two channels. Some characteristics of the 200-W TWT, as demonstrated during the first six months in orbit, were

- Construction: coupled cavity, multistage depressed collector, conduction cooling.
- RF output at saturation: 200-W continuous-wave minimum over the operating band, 240-W peak, 30-dB gain, 3-dB bandwidth ≥ 85 MHz.
- Center frequency: 12.080 GHz.
- Efficiency: 45% at 224-W output (including power supply).

The CTS had redundant receivers, one with a tunnel diode preamplifier and the other with a parametric amplifier. Both receiver chains were single conversion and had a tunnel diode amplifier (TDA) following the mixer. The receivers fed redundant field effect transistor amplifiers that provided the input signals for the TWTs. The satellite had two narrowbeam antennas, one directed toward a control terminal and the other toward remote terminals. The two channels were used for two-way communications. The high-power TWT was used for transmission to the remote terminals that used relatively small antennas.

Canada, NASA, and other United States Government agencies started conducting communication experiments with the CTS following its launch on 19 January 1976. Canada had its control terminal at Ottawa and remote terminals in the north. The capability of the CTS allowed the remote terminals to be relatively small, as indicated by the characteristics given in Table 1. The CTS could support several simultaneous links with these terminals. For example, the 8-ft terminal noted in Table 1 could receive a television signal transmitted with only a quarter of the total CTS power. In May 1976, the CTS was renamed Hermes in Canada. By mid-1978, thirty-two experimental programs had been completed or were in progress and seven more were planned. These experiments were in the fields of propagation, communications engineering, television broadcasting, education, medicine, government, and community affairs. The operational viability of many of these projects was studied further using the 12- and 14-GHz channels on Anik B. CTS was used until November 1979, at which time it was turned off.

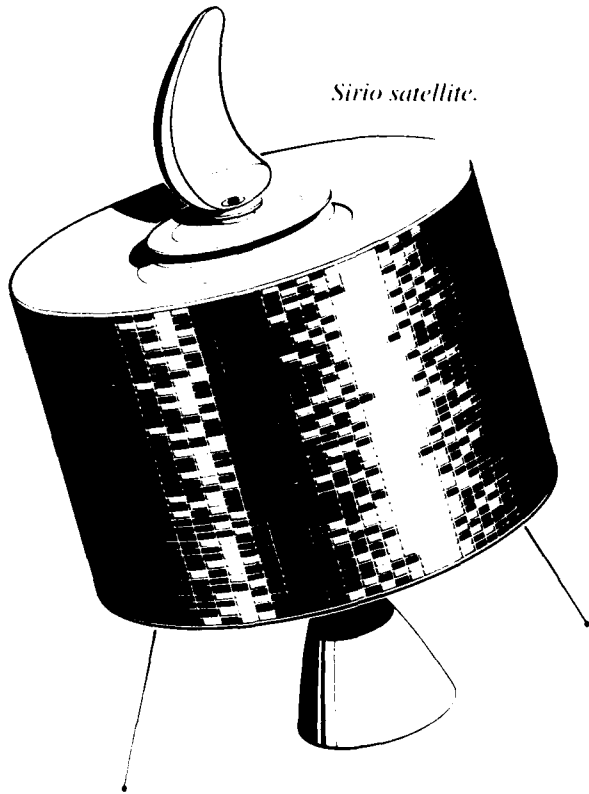
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SIRIO



Sirio satellite.

The Italian industrial research satellite (Sirio) [1-12] was developed for use in propagation and communication experiments at 11.6 and 17.4 GHz. These frequencies were selected prior to the 1971 World Administrative Radio Conference and, therefore, do not exactly coincide with the satellite communication frequency bands defined at the conference. A large part of the Italian aerospace industry participated in construction of the satellite under direction of the Italian National Research Council (CNR). Three ground stations in Italy plus stations in other European countries participated in the Sirio experiments.

The satellite had a cylindrical, spin-stabilized body with a despun antenna on one end. All the equipment was mounted on an internal platform. The payload was primarily for support of the three primary experiments: propagation, narrowband communications, and wideband communications. Secondary experiments were for measurements of the natural environment at synchronous altitude.

In the propagation experiment, the 17.4-GHz uplink was amplitude-modulated at 386 MHz to produce two sidetones 772 MHz apart. In the satellite, they were converted to about 386 MHz with a separation of 20 kHz, and a calibrated reference signal was inserted between them. This combined signal was further converted to 266 MHz and used to amplitude-modulate the 11.6-GHz downlink carrier. The

downlink carrier amplitude was controlled to provide a reference level. This combination of uplinks and downlinks allowed all measurements to be performed on the ground. The measurements made were absolute attenuation at 11.6 and 17.4 GHz, and relative attenuation and phase delay over frequency intervals of 772 MHz and 532 MHz. In addition, multiple ground receivers were used to measure space diversity improvement. Space diversity on the uplink was achieved by having two sidetones transmitted from different locations.

In the narrowband communication mode, as many as 12 bi-phase modulated carriers were transmitted to the satellite by frequency division multiplexing. The data rate on each carrier was 70 kbps, and the satellite bandwidth was 2.5 MHz. In the satellite, the combined signal was amplified at IF and then used to modulate the downlink carrier. The wideband communication mode was similar, except that the satellite bandwidth was 35 MHz. The uplink transmission was a single television channel or high rate digital data.

The satellite was operated in any one of the three modes. The satellite equipment was common for all the modes except for portions of the IF section. The transmitter output power was 10 W from either of two TWTs. The equipment details are as follows:

Satellite

Cylinder, 56-in. dia., 34-in. height (78 in. overall)

480 lb in orbit, beginning of life

Solar cells, 135 W beginning of life, 100 W minimum after two years

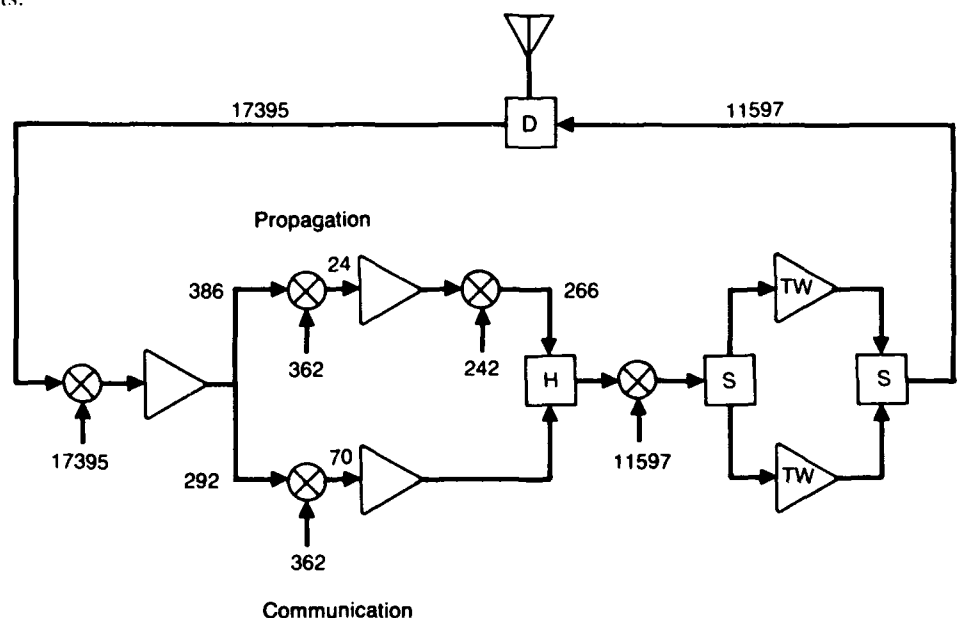
Spin-stabilized, 90 rpm

Solid rocket motor for apogee maneuver, hydrazine thrusters for on-orbit use

Configuration

Communication experiment: 2.5-MHz bandwidth repeater with as many as twelve 70-kbps carriers, or 35-MHz bandwidth repeater with one TV channel

Propagation experiment: 40-kHz bandwidth repeater



Sirio communication subsystem.

Transmitter

11.597 GHz

10-W output TWT (one on, one standby)

ERP: propagation mode, 16 dBW; narrow-band communication, 24 dBW; wideband communication, 26 dBW; all at edge of coverage (all 5 dB higher in central 1 deg of beam)

Receiver

17.395 GHz

G/T: -16 dB/K (-10 dB/K over central 3×5 deg of beam)

Antenna

Fixed feed horn with mechanically despun reflector, >22.5/23.5-dB gain on axis (11.6/17.4 GHz), 6×10 -deg beamwidth (6 deg is north-south beamwidth), beam center 6.5 deg above equatorial plane, steerable 3.5° W to 4.5° E of satellite nadir, circular polarization

Design life

Two years

Orbit

Synchronous equatorial, 15° W longitude, later moved to 12° E longitude; moved to 65° E in early 1983

Orbital history

Launched 25 August 1977, in use until 1985

Delta 2313 launch vehicle

Management

Developed by Italian aerospace industry for CNR (Consiglio Nazionale della Ricerca)

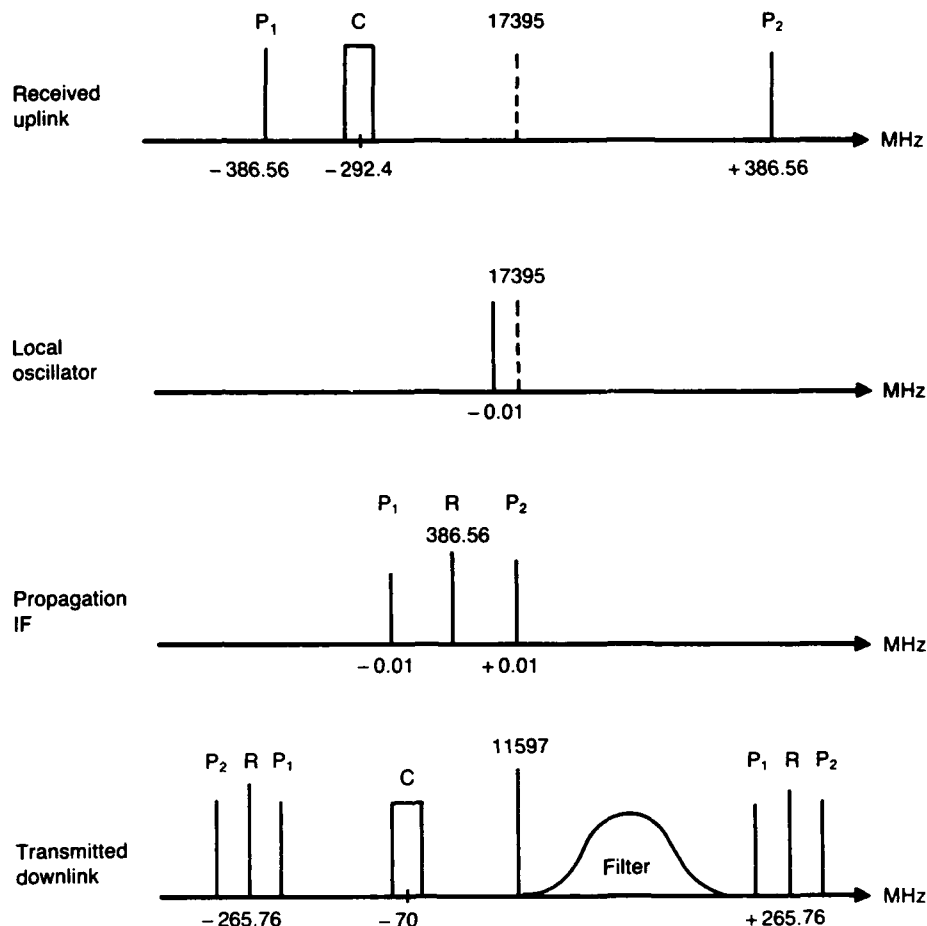
The Sirio experiment was defined in 1968 and was originally scheduled to be launched in 1972. A number of delays occurred as the result of technical, political, and financial reasons. The satellite was launched 25 August 1977 and used in a variety of experiments. In 1983, it was moved to a position over the Indian Ocean for cooperative Chinese-Italian experiments, which lasted until October 1984. Sirio was turned off in 1985.

The Sirio 2 satellite was an ESA program. The satellite was primarily constructed with hardware left over from the basic Sirio program, but the payloads were different. Sirio 2 had an S-band transponder for distribution of meteorological data between ground sites, and a detector and retroreflector for a laser clock synchronization experiment.

The Sirio 2 program started in 1978. The satellite was launched together with a Marecs satellite on an Ariane launch vehicle in September 1982. A failure in the Ariane third stage resulted in the loss of both satellites.

* * * * *

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P_1 , P_2 Propagation tones
 R Reference level tone injected in satellite IF
 C Communication signal
Filter removes upper communication sideband
 P and C are never simultaneous

RF spectra in the Sirio satellite.

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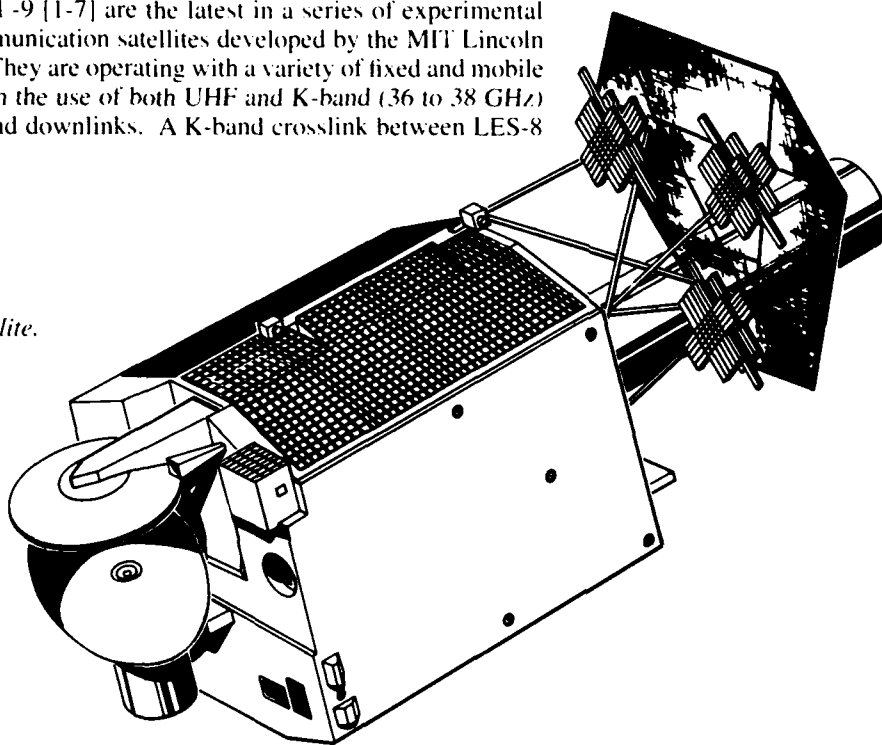
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LINCOLN EXPERIMENTAL SATELLITES (LES)-8 and -9

LES-8 and -9 [1-7] are the latest in a series of experimental military communication satellites developed by the MIT Lincoln Laboratory. They are operating with a variety of fixed and mobile terminals with the use of both UHF and K-band (36 to 38 GHz) for uplinks and downlinks. A K-band crosslink between LES-8

LES-9 satellite.



and LES-9 is a significant part of the program. The communications electronics are all solid state. Two K-band receivers and transmitters are on each satellite, one used with a horn antenna and the other with an 18-in. parabolic reflector. The paraboloid works with a steerable flat plate and a five-horn feed to provide a narrowbeam tracking antenna. This antenna is normally used for crosslink communications but can also be used for uplink/downlink traffic. The satellites can acquire the crosslink with initial pointing uncertainties greater than ± 1 deg and maintain tracking to better than 0.1 deg at typical signal levels. The horn antenna is fixed and is used only for uplinks and downlinks. The K-band transmitters use parallel Impatt diode amplifiers to produce an output power of 0.5 W. The crosslink bit rate is either 10 or 100 kbps, using phase shift keying (PSK) modulation. The K-band uplinks use both eight-tone FSK and differential quadriphase shift keying (DQPSK); the K-band downlinks use DPSK. All UHF transmissions use eight-tone FSK. For transmissions involving UHF links, which are primarily for relatively simple mobile terminals, the basic data rate is 75 bps. The K-band links can handle selected information rates up to 19,200 bps, which is adequate for computer data or digitized voice. Except for an optional UHF frequency translation mode with a bandwidth of 500 kHz, all received uplinks are translated to intermediate frequencies and

then demodulated. All signal routing is controlled by switches set by commands from the ground. The basic routings available are shown in the block diagram.

LES-8 and -9 are practically identical. Most of the electronic subsystems are contained in the satellite body, which is 46 in. long and about 44 in. across. The two radioisotope thermoelectric generators (RTGs) are mounted one upon the other on the back end of the satellite body. These RTGs provide all the electrical power used by the satellite; no solar cells are used. The UHF antenna is also attached to the back end of the satellite body. The K-band antennas and some electronics, plus earth sensors, are mounted on the front end. The overall length of the satellite is about 10 ft. The satellite is three-axis-stabilized by a gimbaled momentum

wheel and ten gas thrusters. The satellite details are as follows:

Satellite

Approximately 10 ft long

LES-9, 948 lb in orbit, beginning of life

LES-8, similar to LES-9

Two RTGs, 152 W each initially, 130 W each after five years (design goal was 145/125 W)

Three-axis stabilization using a gimbaled momentum wheel, ± 0.1 deg about pitch and roll axes, ± 0.6 deg about yaw axis

Cold gas propulsion for on-orbit use

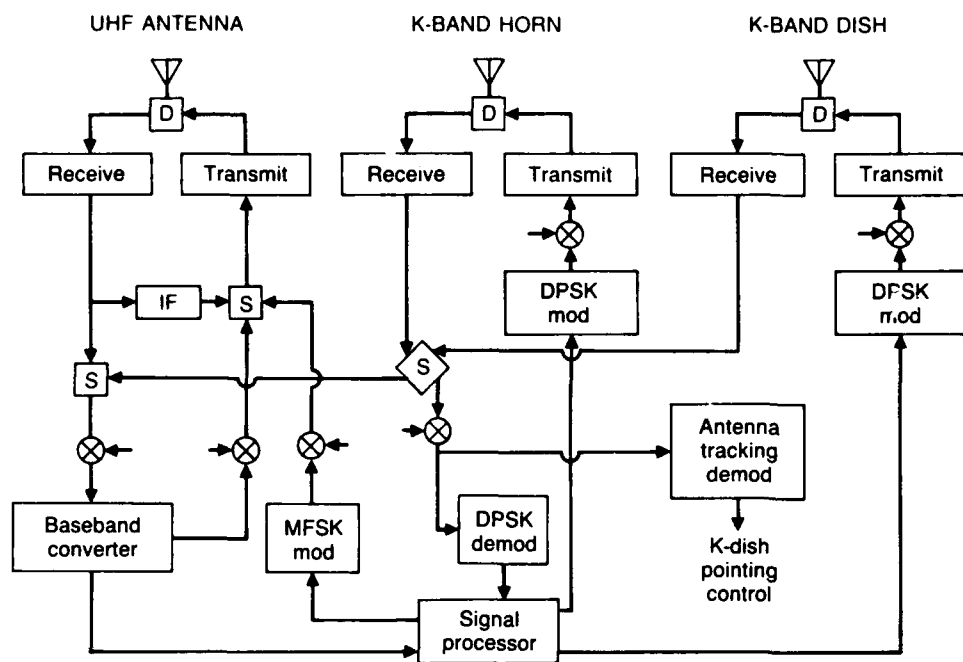
Transmitter

UHF: 240- to 400-MHz band, 32-W or 8-W output, ERP 25 dBW (high power mode) or 18 dBW (low power mode)

K-band: 36- to 38-GHz band; 0.5-W output, 21-dBW ERP (horn); 0.5-W output, 39-dBW ERP (dish)

Receiver

UHF: 240- to 400-MHz band, system noise temperature approximately 1000 K, G/T -20 dB/K



LES-8 and -9 and communication subsystem.

K-band: 36- to 38-GHz band, system noise temperature 1400 K, $G/T \geq -8$ dB/K (horn), ≥ 10 dB/K (dish)

Antenna

UHF: three crossed dipoles on a ground plane, 35-deg beamwidth, approximately 8-dB gain (edge of earth)

K-band: horn, 10-deg beamwidth, 24-dB gain (on axis); dish, 18-in. paraboloid, 1.15-deg beamwidth, 42.6-dB gain (on axis), steerable ± 10 deg in elevation and 104 deg in azimuth by gimbaled flat plate

Orbit

Synchronous, 25-deg inclination, 40°W and 110°W longitude, later collocated near 106°W longitude

Orbital history

Launched 14 March 1976

Titan IIIC launch vehicle

In use (1989)

Management

Developed by MIT Lincoln Laboratory

Operated by MIT Lincoln Laboratory

LES-8 and -9 were launched together on a Titan IIIC booster on 14 March 1976. The first tests showed that all important communications parameter values were in good agreement with the prelaunch measurements. Since then, the satellites have been exercised in a variety of modes, both for detailed performance measurements and for functionally oriented demonstrations to prove the operability of the various links. These tests have involved ground and mobile terminals developed by Lincoln Laboratory, the Air Force, and the Navy. The test results have all been satisfactory and have shown that the LES-8 and -9 communications features are operationally useful. The satellites were still in good condition and being used in 1989.

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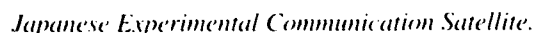
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JAPANESE EXPERIMENTAL COMMUNICATIONS SATELLITE (JECS)

Although Japan had built and launched several low-altitude satellites, their first communications and broadcasting satellites were built in the United States and launched by NASA. At the same time, Japan was developing smaller synchronous orbit satellites and a launch vehicle for them. The launch vehicle was the N rocket, which was based on the 1970 design of the United States Thor-Delta. An improved version, the N-2, was based on the mid-1970s Delta. The first synchronous orbit mission for this launcher was the Engineering Test Satellite-II (ETS-II), the direct predecessor of the Japanese Experimental Communication Satellite

(JECS) that was also launched by the N rocket [1-4]. The objectives of the JECS program were to develop techniques for launch and on-orbit control of synchronous satellites, propagation measurements, and communications experiments.

Both ETS-II and JECS were based on the Skynet I design, because the Skynet was sized to the Delta launch vehicle from which the N rocket was developed; all three satellites were built by the same manufacturer. Like Skynet and ETS-II, JECS was spin-stabilized with a mechanically despun antenna. The solar array was mounted around the outside of the spinning body, and



Satellite

Spin-stabilized, 80 to 115 rpm

Single transponder with selectable bandwidth of 10, 40, or 120 MHz; input and output independently switchable to either C-band or K-band

K-band: 31.65-GHz center frequency,
single 2.5-W TWT, 34-dBW ERP

K-band: 34.83-GHz center frequency, mixer followed by transistor amplifier, -5 dB/K G/T

The two narrowbeam antennas are despun together

Approximately 1.5 years

Synchronous equatorial, 145°E longitude planned, both satellites actually are drifting in near synchronous elliptical orbit

B: launched 22 February 1980, destroyed by apogee motor failure
Japanese N launch vehicle

Developed by Mitsubishi (prime), Ford Aerospace and Communications Corporation (spacecraft and antennas), and Nippon



Electric Company (transponder) for National Space Development Agency of Japan

The communication subsystem of the JECS had five basic sections: C- and K-band receivers (left side of the figure), an intermediate frequency section (middle), and C- and K-band transmitters (right side). The IF section handled only one signal at a time. By ground commands, either transmitter and either receiver could be connected to the IF section, giving a total of four possible configurations. The bandwidth of the IF section could be switched to 10, 40, or 120 MHz. The 10-MHz option was intended for range and range rate measurements and the wider bandwidths for the communications experiments.

JECS was launched in early February 1979 but was destroyed during apogee motor firing, apparently due to a collision with the launch vehicle third stage. The spare JECS was launched a year later and was destroyed by a failure of the apogee motor.

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ENGINEERING TEST SATELLITE (ETS)-V

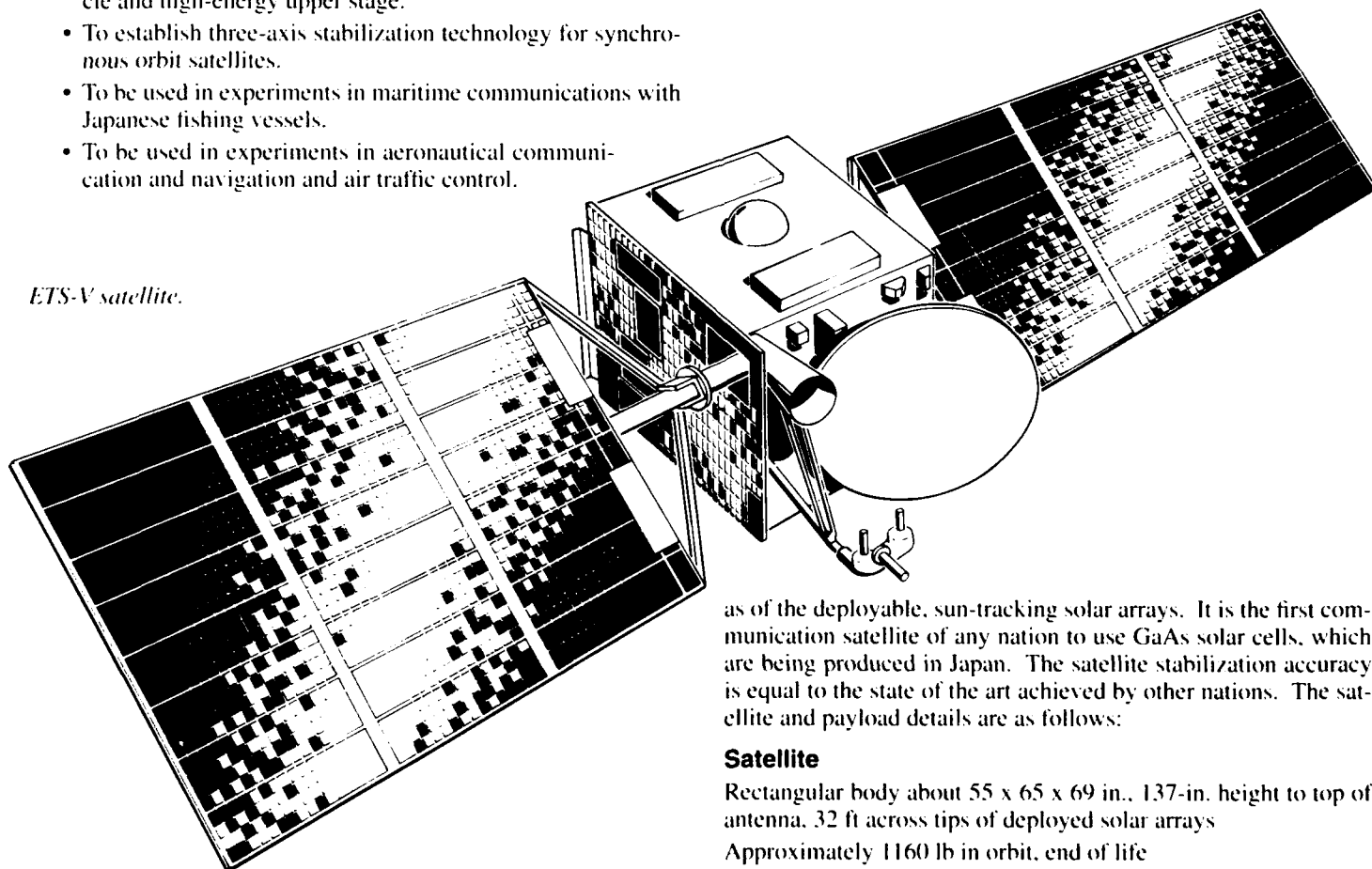
The Japanese national space program has used Engineering Test Satellites (ETS) as a means of proving basic equipment and techniques for satellites, launch vehicles, and satellite control and operations. ETS-V [1-11] is the first of this series to incorporate a communications payload. The ETS-V satellite has four objectives:

- To serve as a test payload for the Japanese H-1 launch vehicle and high-energy upper stage.
- To establish three-axis stabilization technology for synchronous orbit satellites.
- To be used in experiments in maritime communications with Japanese fishing vessels.
- To be used in experiments in aeronautical communication and navigation and air traffic control.

The communications payload of ETS-V, which was used in satisfying the third and fourth objectives, is called the Aeronautical Maritime Experiment Transponder. It is the space segment of the Experimental Mobile Satellite System.

The ETS-V satellite body, the solar arrays, and the antennas are shown. ETS-V is the first Japanese-built three-axis-stabilized satellite and serves as a test of the stabilization subsystem as well

ETS-V satellite.



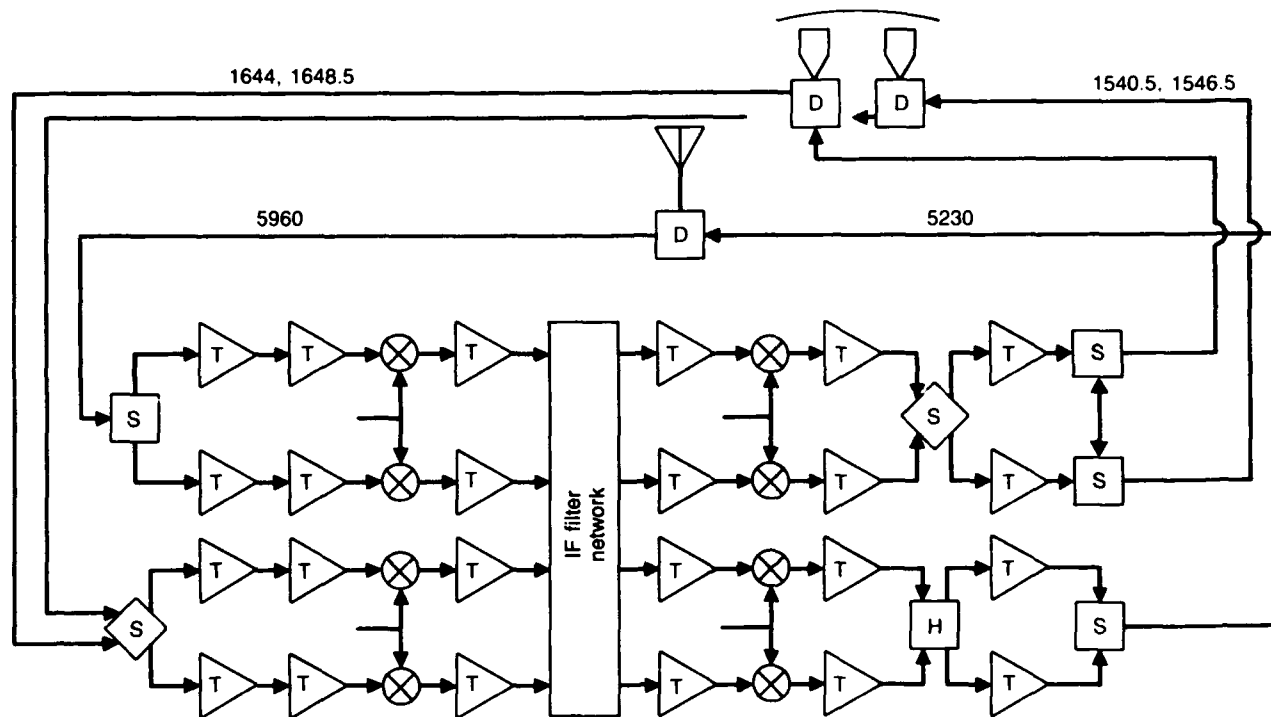
as of the deployable, sun-tracking solar arrays. It is the first communication satellite of any nation to use GaAs solar cells, which are being produced in Japan. The satellite stabilization accuracy is equal to the state of the art achieved by other nations. The satellite and payload details are as follows:

Satellite

Rectangular body about 55 x 65 x 69 in., 137-in. height to top of antenna, 32 ft across tips of deployed solar arrays

Approximately 1160 lb in orbit, end of life

Solar cells and NiCd batteries, 1067 W maximum, beginning of life; 820 W minimum, end of life



ETS-V communication subsystem.

Three-axis stabilized, ± 0.08 deg 3σ (pitch and roll), ± 0.45 deg 3σ (yaw)

Configuration

C/L-band for fixed to mobile terminals, 3-MHz bandwidth

L/C-band for mobiles to fixed, 3-MHz bandwidth

C/C-band for fixed to fixed, 3-MHz bandwidth

L/L-band for mobiles to mobiles, 300-kHz bandwidth

Transmitter

L: 1540.5 to 1543.5 MHz and 1545 to 1548 MHz

Two 25-W FET amplifiers

35.5-dBW per channel ERP on axis

C: 5218.75 to 5241.25 MHz

Two 8-W FET amplifiers

25-dBW ERP on axis

Receiver

L: 1642.5 to 1645.5 MHz and 1647 to 1650 MHz

FET preamps, 1.65-dB noise figure

-4 dB/K minimum G/T on axis

C: 5948.75 to 5971.25 MHz

FET preamps, 2.1-dB noise figure

-8 dB/K G/T on axis

Antennas

L: one 59-in. dia. parabolic reflector, offset fed by two helices to produce two beams, each with approximately 9-deg beamwidth and 25 dB on axis gain, circular polarization

C: one earth coverage horn with approximately 20 dB on axis gain, circular polarization

Design life

Five years (1.5-year fuel load planned)

Orbit

Synchronous equatorial, 150°E longitude, stationkeeping to $\pm 0.1^\circ$ N-S and E-W

Orbital history

Launched 27 August 1987, still operating in 1990

Japanese H-1 launch vehicle

Management

Developed by Mitsubishi Electric Company (prime contractor) and NEC (communication subsystem) for NASDA, Ministry of Posts and Telecommunications, and Ministry of Transport

Operated by NASDA

The payload uses C-band to communicate with fixed ground terminals in Japan and L-band to communicate with mobile terminals, i.e., ships and airplanes. Both antennas as well as an S-band telemetry and command antenna can be seen in the satellite figure. The L-band antenna generates two independent beams, which provide coverage of all Asian coastal waters and seas and about half of the Pacific Ocean. The two beams provide higher gain than a single beam with broader coverage; this gain is necessary to limit the antenna size required on the mobiles.

Because ETS-V is a test satellite, rather than an operational one, the communication subsystem has only partial redundancy. There are four paths through the subsystem, for communication between fixed terminals (C-band receiver/C-band transmit), from fixed to mobile terminals (C/L-band), from mobile to fixed terminals (L/C-band), and between mobile terminals (L/L-band). The path is determined by the uplink frequency, which causes the IF filter network to route the signal to the proper downlink. The IF filters are constructed with surface acoustic wave devices.

The ETS-V satellite development began in 1983. The satellite was launched in 1987. Initial testing showed that the satellite and the payload were operating properly. The primary mobile communications experiments were conducted between earth stations in Japan and a ship and a 747 aircraft. Signal quality was mea-

sured in many conditions, and fading countermeasures were tested. Landmobile communications were conducted with vehicles and trains; three modulation formats were tried.

Following the basic mobile communications experiments, several supplementary experiments have been started. One is a position location test using signals from a mobile station transmitted through both ETS-V and the Pacific Inmarsat. In another experiment, nongovernment organizations used the satellite for mobile communications demonstrations. In addition, Aussat conducted landmobile experiments through the southern L-band antenna beam. The experience gained through the ETS-V experiments will be applied in the future design of an operational mobile communications satellite system.

* * * * *

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ENGINEERING TEST SATELLITE (ETS)-VI

ETS-VI [1-19] is the largest in a series of Experimental Test Satellites developed and launched by Japan. The project has three broad objectives. One is spacecraft technology: to develop and operate a three-axis-stabilized satellite weighing over 4000 lb. Another is to verify the capability of the Japanese H-II launch vehicle by launching ETS-VI on the second flight of the H-II series. A third is to build, and demonstrate in orbit, several communications payloads incorporating new technologies appropriate to future operational missions.

The development aspect of the spacecraft technology objective is carried out both by the basic design features of ETS-VI and by several experiments. The spacecraft body is a rectangular box, with solar arrays, two large antenna reflectors, and one smaller antenna compartment which deploy from it in orbit. The structure is made of composite materials. A bipropellant system is used for the apogee maneuver and in-orbit control, augmented by ion thrusters for north-south stationkeeping. A nickel-cadmium battery is the primary power storage, but ETS-VI also has a nickel-hydrogen battery. The latter is new for Japan, although common in other satellites; whereas the ion thrusters are a new technology for a ten-year life satellite. Other aspects of the ETS-VI attitude control and power use techniques are new to Japan. In addition, the satellite carries a variety of sensors to measure the launch environment and the internal and external environments in orbit.

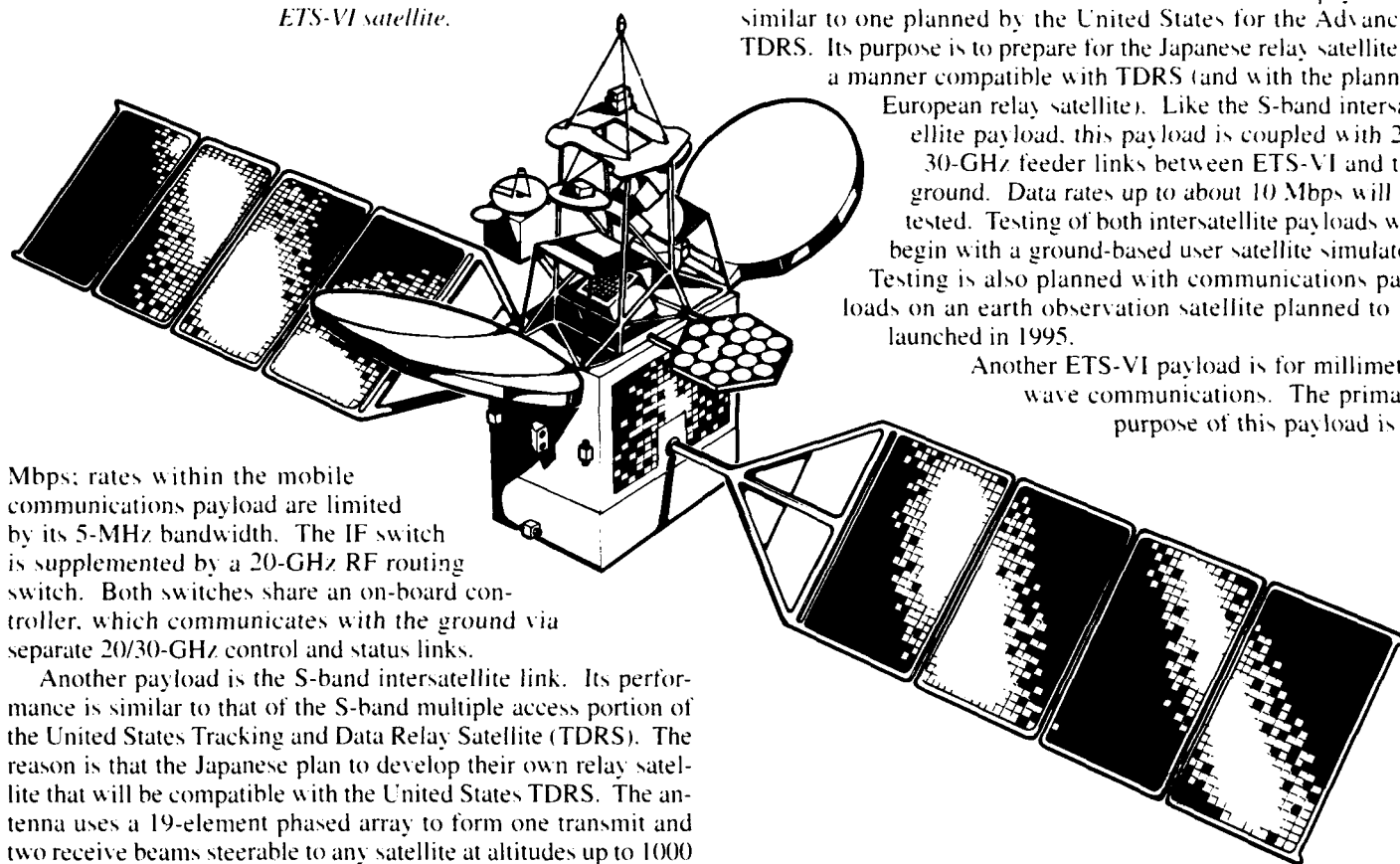
ETS-VI has six communications payloads. The largest is the fixed communications payload, which will demonstrate high-capacity services between fixed-site ground terminals. The primary frequency bands are 20 and 30 GHz. Each is associated with one of the large reflectors, which form very narrow beams. Twelve of

these beams are required to cover the main island of Japan. To reduce the payload weight in order to accommodate other payloads, only four beams are used. Two of these point at Tokyo and Osaka, which are the largest metropolitan areas; the same frequencies are used independently in both beams. This frequency reuse, in addition to dual polarization frequency reuse, will demonstrate the techniques necessary for a very high capacity communications satellite. Being an experiment, this payload does not have as many 20/30 GHz transponders as the spectrum can support. However, it also has one transponder using the 4- and 6-GHz bands. This transponder shares the 30-GHz reflector and has one beam that covers most of Japan. Its purpose is to be an alternate to any of the 20- and 30-GHz transponders and beams, if the traffic exceeds their capacity or if they are temporarily unavailable due to attenuation cause by heavy rain.

The mobile communications payload shares the 20-GHz reflector and has five beams which cover all of Japan plus the ocean areas to 200 miles offshore. The main demonstration with this payload will be communications between small fishing vessels and shore stations. The one transmitter of this payload amplifies the signals for all five beams, dividing its power automatically in proportion to the number of signals in each beam. This feature is important, because the traffic patterns for mobile terminals are variable.

The fixed and mobile communications payloads are connected through an IF switch. This allows signals from any of the 10 up-link beams to be routed to any of the 10 downlink beams. The switch is fast enough to route individual time division multiple access (TDMA) bursts to different beams. Within the fixed communications payload, the TDMA rate will be as high as 200

ETS-VI satellite.



Mbps; rates within the mobile communications payload are limited by its 5-MHz bandwidth. The IF switch is supplemented by a 20-GHz RF routing switch. Both switches share an on-board controller, which communicates with the ground via separate 20/30-GHz control and status links.

Another payload is the S-band intersatellite link. Its performance is similar to that of the S-band multiple access portion of the United States Tracking and Data Relay Satellite (TDRS). The reason is that the Japanese plan to develop their own relay satellite that will be compatible with the United States TDRS. The antenna uses a 19-element phased array to form one transmit and two receive beams steerable to any satellite at altitudes up to 1000 km (540 nmi). In the satellite drawing, the phased array is the flat hexagonal panel to one side of the antenna tower. These S-band intersatellite links are coupled with 20- and 30-GHz feeder links to and from the ground; together they will provide two-way communications between ground stations and low orbit satellites. Transmissions will be PSK with code division multiple access. Bit rates up to 1.5 Mbps are possible, but rates under 300 kbps will be used most of the time.

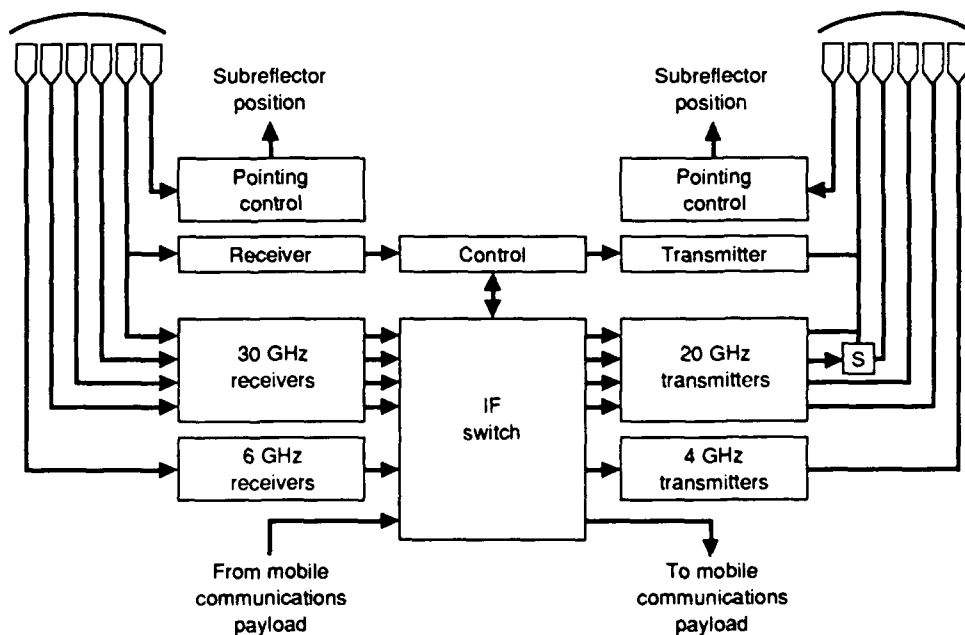
Another intersatellite link payload uses Ka-band; 23 GHz for a

link from ETS-VI and 26 GHz for a return link. This payload is similar to one planned by the United States for the Advanced TDRS. Its purpose is to prepare for the Japanese relay satellite in a manner compatible with TDRS (and with the planned European relay satellite). Like the S-band intersatellite payload, this payload is coupled with 20/30-GHz feeder links between ETS-VI and the ground. Data rates up to about 10 Mbps will be tested. Testing of both intersatellite payloads will begin with a ground-based user satellite simulator. Testing is also planned with communications payloads on an earth observation satellite planned to be launched in 1995.

Another ETS-VI payload is for millimeter wave communications. The primary purpose of this payload is to

demonstrate communications with very small earth terminals, e.g., as small as a 1-ft diameter antenna and 0.5-W transmitter. Another application is for an intersatellite link, which can be demonstrated with a ground-based simulator. This payload uses 38 GHz for transmissions from ETS-VI and 43 GHz to ETS-VI. The data rate with small earth terminals will be about 64 to 512 kbps; for intersatellite demonstrations it will be 10 Mbps. The attenuation due to rain is very high at these frequencies, but many

ETS-VI fixed communications payload.



of the applications postulated for the small earth terminals do not require continuous communications and are able to tolerate outages during storms. The millimeter wave payload is small—a 16-in. antenna and a weight of 22 lb. It is mounted on the same platform as the Ka-band intersatellite payload. A single pointing mechanism steers the platform and will provide the antenna pointing control for both payloads. These payloads are mounted on the side of the antenna tower opposite the S-band phased array. The millimeter wave payload is also connected to the 20/30-GHz feeder links for communications with the primary experiment ground terminals.

ETS-VI also has an optical communications payload. The aim of this payload is to demonstrate technology for an intersatellite link, but it will be tested only with a ground terminal. The payload has a 3-in. diameter telescope; the ground telescope diameter is 60 in. The uplink will use an argon laser, the downlink a GaAlAs diode laser. The data rate will be 1 Mbps. The payload uses a two-stage control loop. A charge-coupled device array detector provides coarse pointing information to the outer loop, which controls a gimbaled flat mirror. A quadrant detector provides fine pointing information to an inner loop, which controls the fine pointing mechanism. Pointing accuracy while autotracking the uplink is expected to be 2 μ rad (one ten-thousandth of a degree).

Development of ETS-VI began in 1987. Structural and thermal tests of satellite engineering models were conducted in 1989 and 1990. Launch is planned for 1993. Additional details are as follows:

Satellite

Rectangular body 6.6 \times 9.8 \times 9.2 ft, 100 ft across the deployed solar arrays, 26-ft height of body plus antenna tower
4400 lb in orbit, beginning of life

Sun-tracking solar arrays, NiCd battery (operations), NiH₂ battery (test), approximately 4500 W beginning of life, 4100 W minimum end of life

Three-axis-stabilized, ± 0.05 -deg accuracy in pitch and roll, ± 0.15 -deg accuracy in yaw

Unified liquid bipropellant propulsion for apogee maneuver and on-orbit use, plus ion propulsion for north-south stationkeeping

Configuration

Fixed communications payload (FC): multiple 200-MHz bandwidth transponders at C-band (4/6 GHz) and Ka-band (18/30 GHz) connecting multiple beams through an IF switch, dual-polarization and dual-beam frequency reuse

Mobile communications payload (MC): five beams connected through a single 5-MHz bandwidth S-band (2.5/2.6 GHz) transponder

S-band Intersatellite Link payload (S-ISL): one forward transponder with 5-MHz bandwidth, one return transponder with 5-MHz bandwidth

Ka-band Intersatellite Link payload (K-ISL): one forward transponder and one return transponder

Millimeter Wave payload (MMW): one forward transponder and one return transponder

Optical payload (Opt): duplex communications, 1 Mbps data rate
S-ISL, K-ISL, and MMW are each connected with 30-GHz (uplink) and 20-GHz (downlink) feeder links through a 2-GHz IF switch network; the two transponders within each of these payloads can be connected to each other as an alternative to the feeder link connections

Transmitter

FC: 3.82 GHz (H polarization), 4.08 GHz (H), 17.885 GHz (V and H), 18.365 GHz (V)

7-W SSPAs at 4 GHz

10-W TWTAs at 18 GHz, plus 4-W SSPA near 20 GHz for a downlink associated with the ISL and MMW payloads

MC: 2502.5 MHz

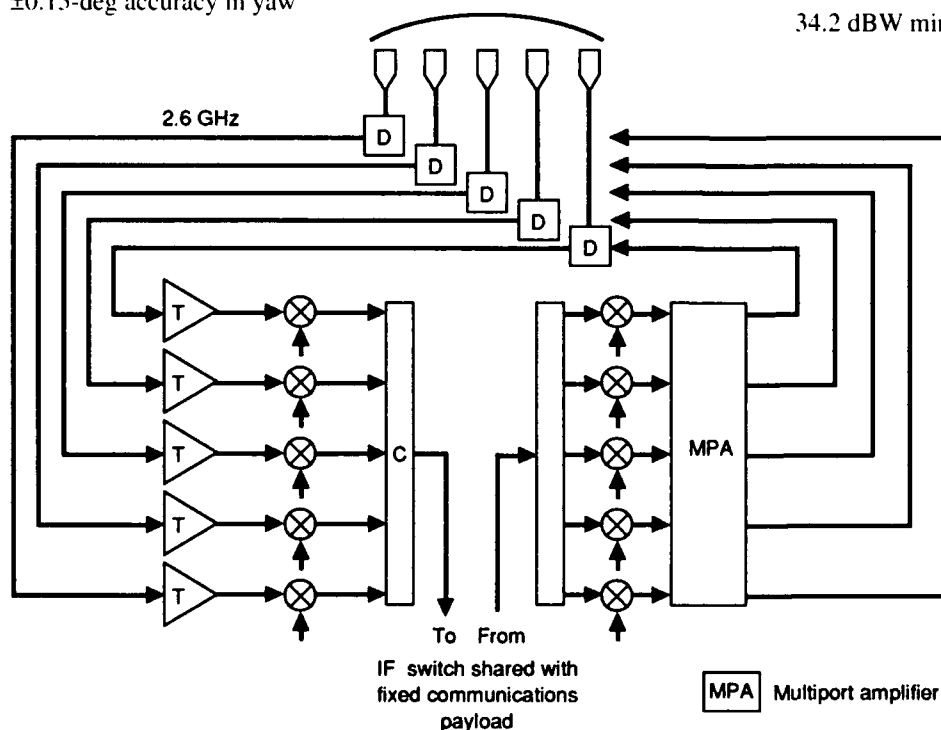
8 GaAs FET power amplifiers

100-W total output power flexibly shared among beams

S-ISL: 2108.4 MHz

0.9-W SSPA for each of 16 antenna elements

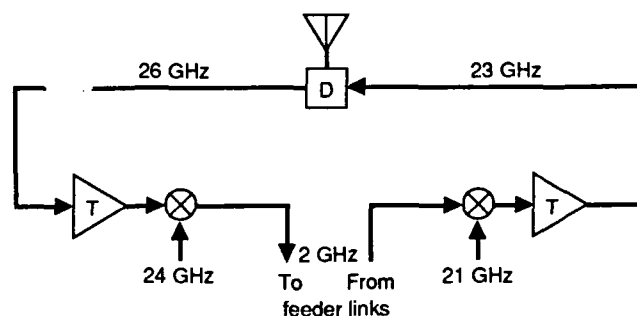
34.2 dBW minimum total ERP



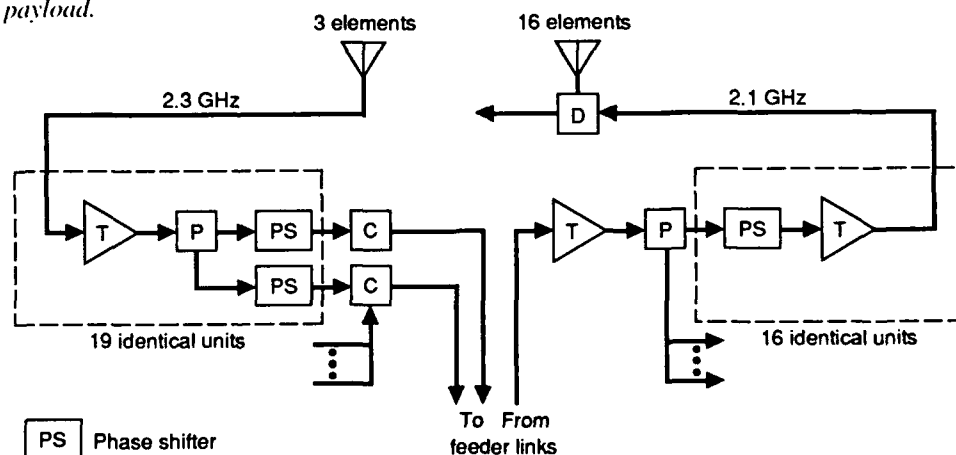
ETS-VI mobile communications payload.

Avalanche photo diode

S-ISL: 19-element phased array, elements arranged in a hexagonal pattern, 5.8 ft across corners; all 19 elements used to form two receive beams, 16 elements used to form one transmit beam; element gain $\geq 14.8/14.5$ dB (receive/transmit); total gain $>27.3/26.2$ dB (receive/transmit); beams steerable ± 10 deg, pointing error <1.1 deg; circular polarization



ETS-VI S-band intersatellite link payload.



K-ISL: 31.5-in. dia. parabola, ± 0.2 -deg pointing accuracy with autotracking, steerable ± 9.8 deg, circular polarization

MMW: 16-in. dia. parabola, 37/41 dB gain (transmit/receive), mounted on same steerable platform as Ka-ISL antenna, circular polarization

Opt: 3-in. dia. gimbaled telescope, 30 or 60 μ rad (1.7 or 3.4 mdeg) transmit beamwidth; two-stage pointing with autotrack, coarse pointing accuracy 32 μ rad, fine pointing accuracy 2 μ rad

Design life

Ten years

Orbit

Synchronous equatorial, stationkeeping to $\pm 0.1^\circ$ N-S and E-W

Orbital history

Launch scheduled summer 1993, will go to 154° E longitude

Japanese H-II launch vehicle

Management

Developed for NASDA by Toshiba (spacecraft), NTT (FC and MC payloads), and others

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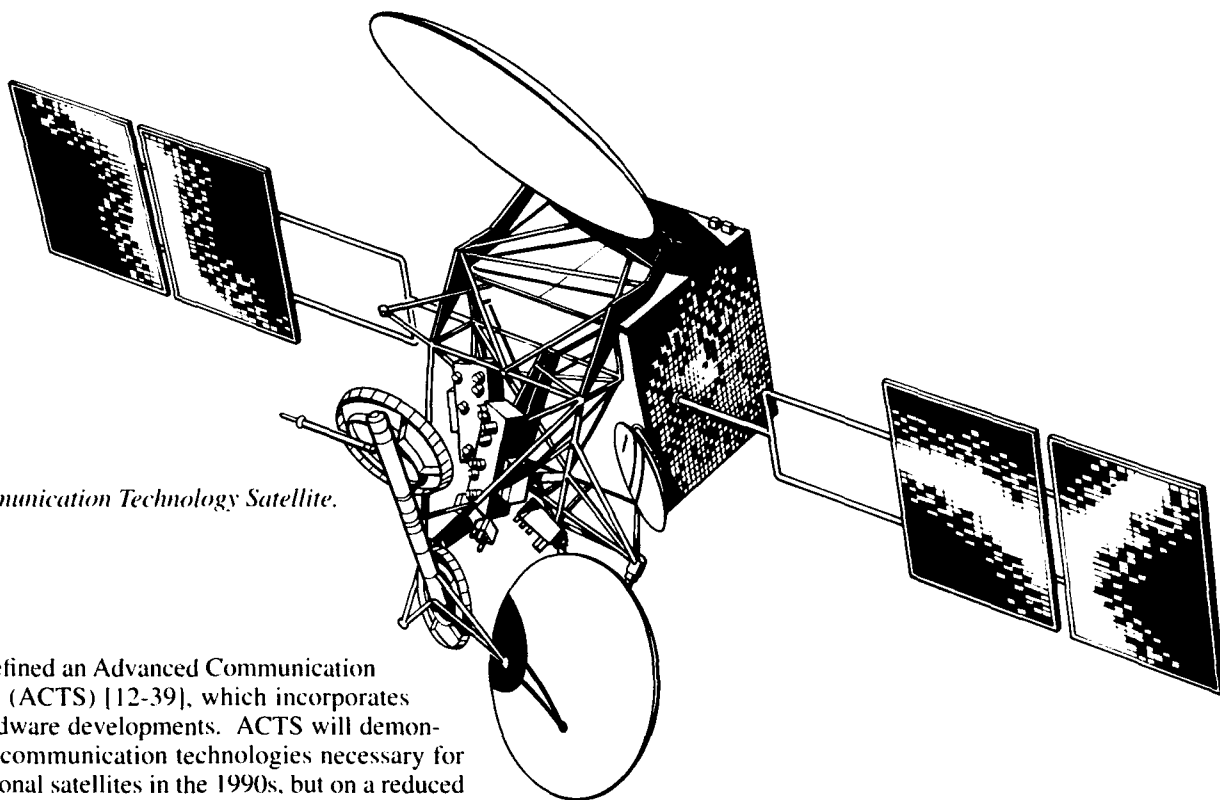
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ADVANCED COMMUNICATIONS TECHNOLOGY SATELLITE (ACTS)

In 1973, NASA greatly reduced its efforts in communications technology, primarily because of budget restrictions. Private industry supported some developments with short-term (e.g., a few years) potential for commercial success. However, private industry could not support the higher risk, higher potential developments which require about a decade to bring to commercial usefulness. Because of this, and with urgings from many directions, NASA was able to resume its support of communications technology in 1978.

The major item in the new program is a high-capacity domestic communications satellite in the 30- and 20-GHz bands. This became known as the 30/20-GHz program [1-11]. Market analyses and system studies were carried out first. Then in 1980, several hardware developments were undertaken. These included a multibeam antenna with both fixed and scanned beams, a baseband processor, an IF switch matrix, a traveling wave tube amplifier (TWTA), and a low noise receiver. The initial phases of these developments were completed by 1984.



Advanced Communication Technology Satellite.

In 1983, NASA defined an Advanced Communication Technology Satellite (ACTS) [12-39], which incorporates the results of the hardware developments. ACTS will demonstrate all the critical communication technologies necessary for high-capacity operational satellites in the 1990s, but on a reduced scale. An operational satellite will probably have six to twelve times the number of beams, channels, and total capacity as ACTS. The ACTS program includes the following:

- Demonstration of the new technology items on the spacecraft (multibeam antenna, IF switch matrix, baseband processor, high-power TWTA, and low-noise receiver).
- TDMA network control and operations experiments.
- Tests of ground terminal hardware.
- Tests of error correction and power control to minimize degradations caused by atmospheric attenuation.
- Propagation measurements.

The ACTS support subsystem within the central body of the satellite and the deployed solar arrays are based on flight-proven designs. The two large reflectors are attached to the central body of the spacecraft and are deployed in orbit. The smaller subreflectors are mounted on a mast extending forward of the central body and do not require deployment. The feed arrays for the two antennas are mounted on the front face of the central body. Other communications equipment is mounted within the body. Satellite and communication subsystem details are as follows:

Satellite

Rectangular body $80 \times 84 \times 75$ in., 47 ft across deployed solar arrays, 30 ft across deployed reflectors

3270 lb in orbit, beginning of life

Sun-tracking solar arrays, batteries, 1770 W maximum, beginning of life; 1400 W minimum, after four years

Three-axis-stabilized using momentum wheels, antenna pointing accuracy ± 0.025 deg

Solid rocket motor for apogee maneuver, hydrazine thrusters for on-orbit use

Configuration

Three fixed beams interconnected by a 3×3 IF switch matrix

Two scanned beams interconnected by a baseband processor

Capacity

220 Mbps per fixed beam

110 Mbps or 2×27.5 Mbps per scanned beam

Transmitter

19.2 to 20.2 GHz

Four 46-W TWTAs, three active, each switched to one fixed or scanned beam or to the mechanically steerable beam

ERP: 59 to 61 dBW per fixed or scanned beam, 53 dBW on steerable beam

Propagation beacons to 20.185, 20.195, and 27.505 GHz; solid-state amplifiers, 0.18 W (20.185, 20.195 GHz), 0.08 W (27.5 GHz); ERP over CONUS 17.5 dBW (20.185, 20.195 GHz), 14.2 dBW (27.5 GHz)

Receiver

29 to 30 GHz

Three active receivers plus one spare

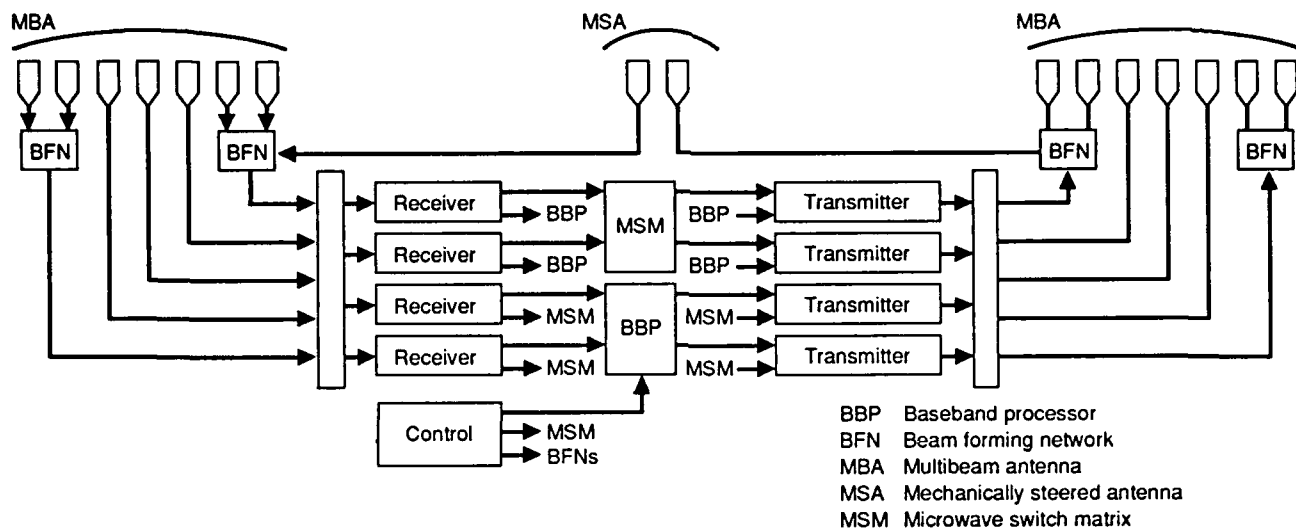
HEMT preamplifiers

3.5-dB receiver noise figure

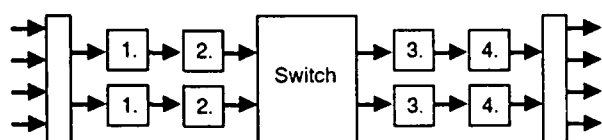
G/T: 15 to 19 dB/K (multibeam antenna), 11 dB/K (mechanically steered antenna)

Antennas

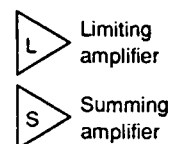
Two offset-fed Gregorian multibeam antennas with 130-in. (20-GHz) and 87-in. (30-GHz) dia. main reflectors, 0.3-deg beamwidth, orthogonal linear polarizations used on each antenna; each reflector has 47 feed horns split between the two polarizations; three for the fixed spots, 13 for the isolated scanning positions, and 31 for the sector scan; 25-dB cross-polarization isolation between beams, 25-dB co-polarization isolation between beams separated by more than one beamwidth



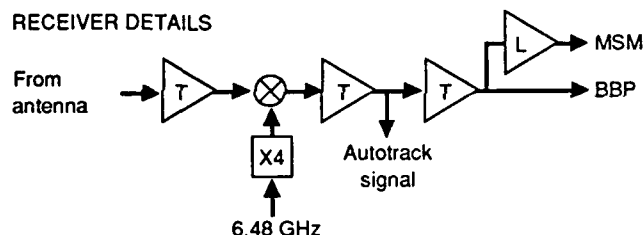
BASEBAND PROCESSOR DETAILS



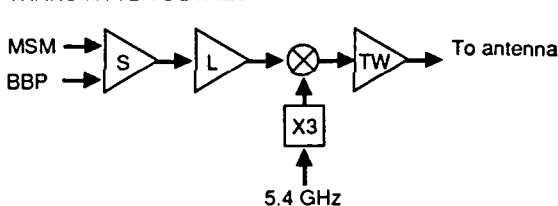
1. Demodulators
2. Memories and decoders
3. Memories and coders
4. Modulators



RECEIVER DETAILS



TRANSMITTER DETAILS



ACTS communication subsystem.

One 43-in. dia. offset-fed parabolic steerable antenna: 44-dB gain (receive), 42-dB gain (transmit); 1-deg beamwidth; linear polarization; one feed horn each for transmit and receive, feed horns are coupled to beam forming networks of multibeam antennas; antenna steerable ± 10 deg in azimuth and elevation

Design life

Four years

Orbit

Synchronous equatorial, planned location 100°W

Orbital history

Launch scheduled February 1993

Shuttle launch vehicle

Management

Developed by GE Astro-Space (formerly RCA) for NASA

Operated by GE Astro-Space (spacecraft control), NASA (communications control)

The ACTS communication subsystem is composed of multi-beam antennas and multimode electronics. The two large antennas, one for transmission and one for reception, each can form

five beams. Three beams are fixed, pointed at Cleveland, Atlanta, and Tampa. The Cleveland uplink beam is used by the ACTS autotracking receiver to keep the antennas accurately pointed. The other two beams are scanning beams. Each scans one contiguous area in the northeast United States and either six or seven specific metropolitan areas in other parts of the country. The scanning is controlled by beam-forming networks which switch among the multiple feed horns for each scanning beam; the switching can be accomplished in less than one microsecond. Uplink and down-link scanning patterns are independent. A separate, mechanically steerable antenna forms a single beam that can be steered toward any point in the 50 states. This antenna is operated as part of the scanned beam capability.

The communications electronics can process signals from any three of the five beams, three fixed and two scanned. The electronics have two separate paths, corresponding to two operating modes for the communication links. The high burst rate mode is associated with the microwave switch matrix. This 4×4 matrix operates at an intermediate frequency slightly above 3 GHz and interconnects the four receivers and four transmitters. Only three are active at a time; the fourth is redundant. The microwave switch matrix will usually be operated with the three fixed beams, but one or two can be replaced by scanned beams. Signals are

typically serial minimum shift keyed (SMSK) at 220 Mbps, but other modulation formats will be tested. The matrix switches in synchronism with TDMA burst transmissions from as many as 10 ground terminals. The TDMA framelength is 1 msec, and the burst switching pattern can be changed as often as once a minute. Uplink power control is used to counter the effects of variable propagation losses.

The low burst rate mode is associated with the baseband processor portion of the communication subsystem. The processor accepts either one 110 Mbps or two 27.5 Mbps inputs from each scanned beam. The inputs are at approximately 3.3 GHz; the two lower rate inputs are at separate frequencies. During increased propagation losses, the data rate can be reduced by a factor of four and rate 1/2 coding applied to produce symbol rates of 110 Msps or 13.75 Msps. The transmission format is TDMA with SMSK modulation. The input bursts are demodulated, and decoded if necessary; the resulting 64-bit words are routed through buffer memories to a data routing switch. The switch sends the 64-bit words through output buffer memories to two modulators. The downlink burst transmission rate is, independently in each beam, either 110 Mbps uncoded or 27 Mbps encoded to 55 Msps.

The satellite also has two propagation beacons at 20 GHz and one at 27.5 GHz. The 20-GHz beacons have telemetry subcarriers. All three beacons can be used for power monitoring for power control or coding decisions for fade compensation on the main links, and for propagation research.

The ACTS spacecraft control center is in New Jersey, but command and telemetry links are routed via terrestrial lines between this center and NASA's master ground station in Cleveland. This station handles the satellite command and telemetry transmissions, controls the communications payload and the network of users, and records system data. It also is a terminal for both low burst rate and high burst rate operations. Many other ground terminals are being provided by experimenters for both communications and propagation applications.

The ACTS contract was awarded in 1984. However, in that year and in most years since, the program has had ups and downs in the budget process, even being completely eliminated and then restored. The scheduled launch date is 1992. NASA has been working with corporations and universities which are defining experiments to be conducted using ACTS.

* * * * *

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ADVANCED RELAY AND TECHNOLOGY MISSION

The Advanced Relay and Technology Mission (Artemis) [1] is an ESA communications technology satellite. Its purpose is to demonstrate new technologies in orbit, which can then be transferred to operational satellites later in the 1990s. This purpose, and some of the specific technologies, are similar to the NASA ACTS and Japan's ETS-VI. The Artemis satellite will demonstrate new technology in three categories: data relay, mobile services, and spacecraft subsystems.

The data relay technologies are lasercom and an S-band high gain multiple access payload. The lasercom is to operate at 65 Mbps using solid-state laser diodes. The eventual goal is a crosslink demonstration from the French Spot 4 earth resources satellite in low orbit to the geosynchronous Artemis satellite. The S-band payload is similar to the one on NASA's TDRS but can accommodate higher data rates.

The mobile services technology is a demonstration of spot beams and frequency reuse with a large L-band reflector antenna. The spacecraft technology items are ion propulsion, a European-built nickel-hydrogen battery, a new star sensor, a gyro, and a diagnostics package. The last item will measure spacecraft vibrations, contamination, and charging. The satellite is also planned to have propagation beacons at 45, 90, and 135 GHz.

Spacecraft configuration and payload definition studies were conducted in 1989 to 1990. The spacecraft weight in orbit is expected to be approximately 2000 lb. Spacecraft development began in 1990, and it will probably be launched in 1995.

* * * * *

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INTERNATIONAL SATELLITES

International satellites are of three types. The first, described here, is part of the global communication networks of Intelsat and Inmarsat. Both networks have at least one satellite over each of the three major oceans (Atlantic, Indian, Pacific) to provide nearly universal coverage (except in polar regions). Both networks also are open to use by all nations. Another type of international satellite is called a regional satellite. Each is designed for and used by a group of countries that have either geographical proximity or cultural ties, or both. These regional satellites are described later. A third type of international satellite is used by private international systems. These systems are operated by private businesses in contrast to the other systems, which are operated by consortia of governments or government-designated organizations.

Intelsat began developing satellites for international public use as soon as the early experimental communication satellites had proven the technology. Starting from a single satellite, the Intelsat system has grown to a global network using many satellites. Six generations of satellites have been brought into service, and a seventh is in development. Each of these satellites is described. In addition, since Intelsat is an outstanding, continually growing

example of the commercial application of space technology, an overall system description is included.

Inmarsat took much longer to come into being than Intelsat. At the start of the 1960s, there were demonstrations of satellite communications with ships. Demonstrations with aircraft followed later in that decade. Through the 1960s and 1970s, there were many studies of satellite systems for maritime and aeronautical communications. However, it was not until 1979 that the Inmarsat organization was formed. It began operations in 1982 with leased capacity. In 1990, the first of its second-generation satellites was launched and development of the third generation began. The Inmarsat system and satellite characteristics are described.

Proposals for private international systems were made in the mid-1980s by several United States companies. Intelsat opposed them, but eventually the United States Government allowed them to develop their systems subject to stated restrictions. The first of these systems is in operation and the second is developing its satellites. The policy issues concerning these systems are discussed and their satellites are described.

EARLY BIRD (INTELSAT I)

In August 1964, the International Telecommunication Satellite Consortium (now called Intelsat) was formed with the goals of production, ownership, management, and use of a global communication satellite system. The feasibility of satellite communications had already been proven, and Intelsat decided to launch a satellite to gain information in four areas:

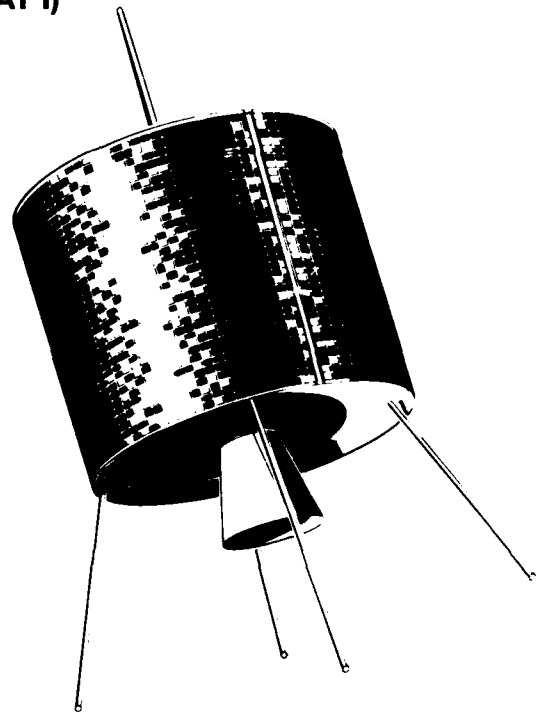
- Rain margins required at ground stations
- Reaction of telephone users to the transmission delay
- Long-term operation of the stationkeeping control valves
- Applicability of communication satellites for commercial telephone use

The satellite was basically experimental to provide some results in these areas of uncertainty. If the results were favorable, the satellite would be put into operational use. Because of the success of Syncom, Intelsat decided to use a satellite of similar design. However, at the same time, three design studies were initiated, covering the three possible orbital modes for a fully operational system. The three choices were: randomly spaced medium altitude satellites, gravity-gradient-stabilized medium altitude satellites with controlled phasing, and larger satellites in synchronous equatorial orbits.

The Early Bird design [1-10] basically followed the Syncom 3 design. The bandwidth and radiated power were increased to provide better service, including two-way television. Larger solar cell panels were used, increasing the satellite height. Since the satellite was to be used for transmission between North America and Europe, the antenna pattern was shaped to service the Northern Hemisphere. Maximum gain occurred at 45°N latitude, rather than at the equator. The satellite had two independent repeaters: one for transmissions from Europe to North America and the other for the opposite direction. The satellite details are as follows:

Satellite

Cylinder, 28-in. dia., 23-in. height



Early Bird satellite.

85 lb in orbit, beginning of life

Solar cells, 45-W maximum, 33-W minimum after three years (NiCd batteries are not used by the communication subsystem)

Spin-stabilized

Solid rocket motor for apogee maneuver

Configuration

Two 25-MHz bandwidth double conversion repeaters

Capacity

240 two-way voice circuits or one two-way TV circuit

Transmitter

4081 MHz to United States, 4161 MHz to Europe

Two TWTs (one on, one standby)

6-W output, 10- to 11-dBW ERP per repeater

Receiver

6390 MHz from United States, 6301 MHz from Europe

9-dB noise figure

Antenna

Transmit: six-element colinear slot array, 9-dB gain, 11- × 360-deg beam tilted 7 deg above equatorial plane (maximum gain at about 45°N latitude)

Receive: Three-element cloverleaf array, 4-dB gain, 40- × 360-deg beam

Design life

1.5 years

Orbit

Synchronous equatorial

Orbital history

Launched 6 April 1965

Commercial service use from 28 June 1965 to January 1969 and from 29 June to 13 August 1969 (to fill coverage gap caused by Intelsat IIIB outage)

Delta launch vehicle

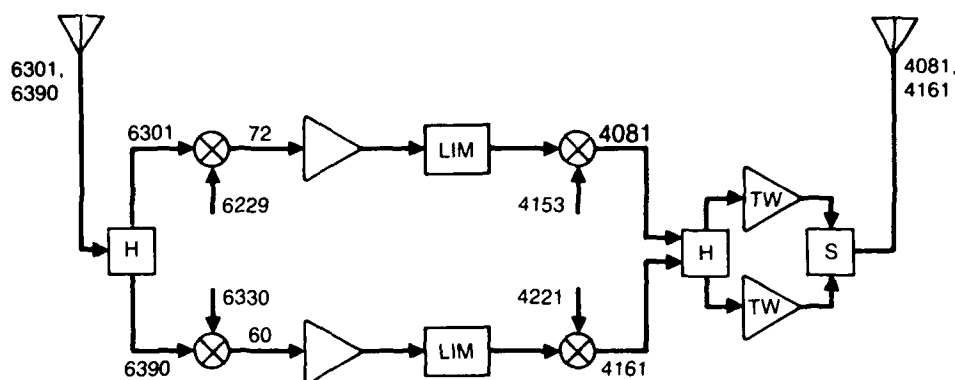
Management

Developed by Hughes Aircraft Company for Comsat Corporation/Intelsat

Operated by Comsat Corporation for Intelsat

Early Bird (also called Intelsat I) was launched in April 1965. Extensive tests were conducted using stations in Maine, England, France, and Germany, which had also operated with Telstar and Relay. Noise, intermodulation, and frequency response measurements were made with single and multiple carriers with voice and television signals. Optimal operating points for ground equipment were determined. The tests indicated that operation to commercial standards could be maintained. DoD also conducted limited tests using Early Bird.

Early Bird was put into regular commercial service in June 1965 and operated regularly until January 1969. In July and August 1969, it was used again during a temporary outage of Intelsat IIIB.



Early Bird communication subsystem.

* * * * *

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INTELSAT II

Intelsat II [1-6] was developed as a follow-on to Early Bird (Intelsat I). A prime factor in the timing of the Intelsat II program was the NASA need for multichannel communications with overseas ground and shipborne tracking stations to aid the Apollo program. Formerly, these communication links depended on high frequency radio, but the increase in manned space flights required improved quality and reliability. The Intelsat II satellites were designed to satisfy NASA requirements and to have additional capacity for other commercial traffic.

The design of the Intelsat II satellite was derived from the Syncom 3 and Early Bird designs. Mechanically, all three satellites were similar. The communication subsystem of Intelsat II had a single, wide bandwidth repeater rather than the pair of narrow-band repeaters used on Early Bird. The antenna pattern was centered at the equator to provide equal coverage to both Northern and Southern Hemispheres. Parallel TWTs were used in the transmitter to compensate for this wider beamwidth (the Early Bird antenna pattern covered only the Northern Hemisphere). Therefore, the communication capacity of Intelsat II was the same as that of Early Bird. The Intelsat II satellite details are as follows:

Satellite

Cylinder, 56-in. dia., 26.5-in. height (45 in. overall)
192 lb in orbit, beginning of life
Solar cells and NiCd batteries, 85 W initially, 75 W minimum after five years
Spin-stabilized
Solid rocket motor for apogee maneuver

Configuration

One 130-MHz bandwidth single-conversion repeater

Capacity

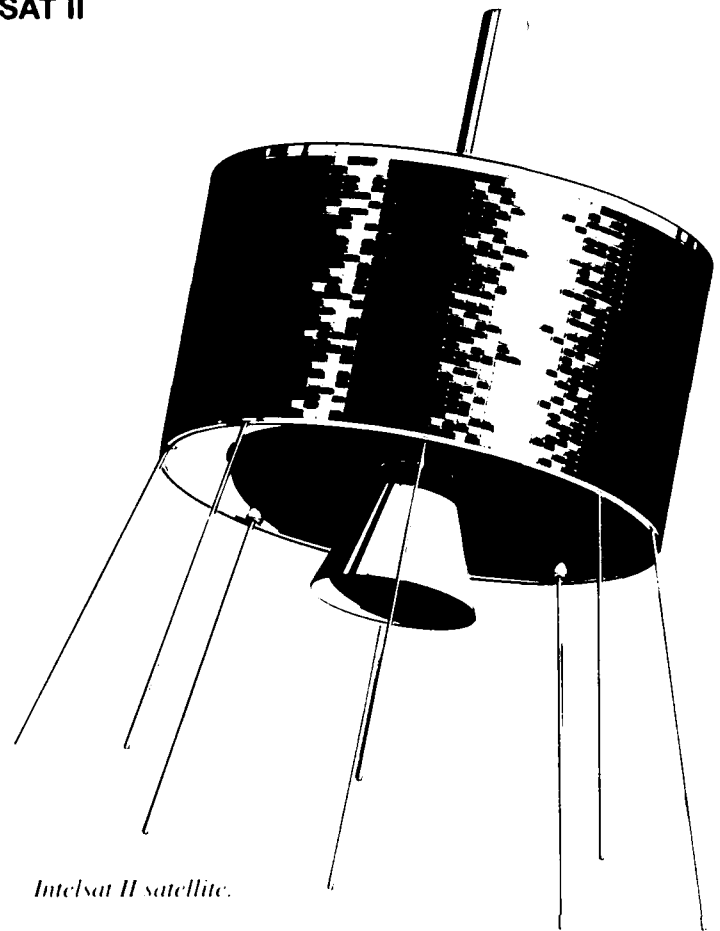
240 two-way voice circuits

Transmitter

4055 to 4185 MHz
Four 6-W TWTs; any combination of one, two, or three active;
12-W output, 15.4-dBW EIRP with two TWTs on

Receiver

6280 to 6410 MHz



Intelsat II satellite.

Redundant: one on, one standby

6-dB noise figure

Antenna

Transmit: four-element biconical horn array, 5-dB gain, 12- to 360-deg beamwidth

Receive: single biconical horn, 4-dB gain

Design life

Three years

Orbit

Synchronous equatorial

Orbital history

Satellite, launch dates, service area, and comments:

IIA, 26 October 1966, failed to achieve synchronous orbit, 12-hr orbit allowed 4 to 8 hr use per day until IIB was launched, decayed from orbit on 7 September 1982

IIB, 11 January 1967, Pacific, retired in early 1969

IIIC, 7 April 1967, Atlantic, retired in February 1970

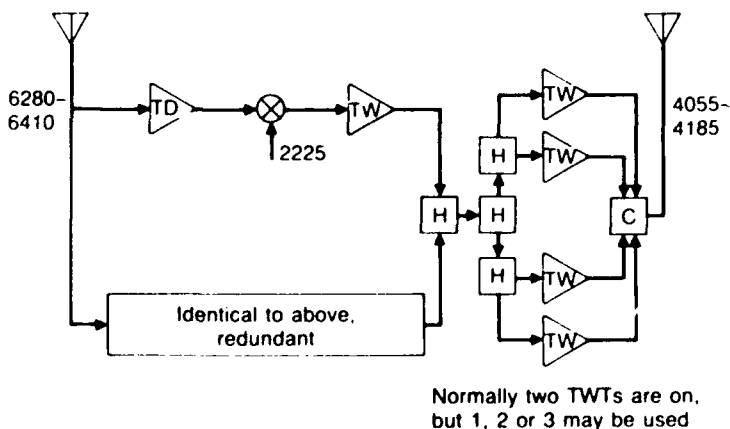
IID, 27 September 1967, Pacific, retired in 1971

Delta launch vehicle

Management

Developed by Hughes Aircraft Company for Comsat Corporation/Intelsat

Operated by Comsat Corporation for Intelsat



Intelsat II communication subsystem

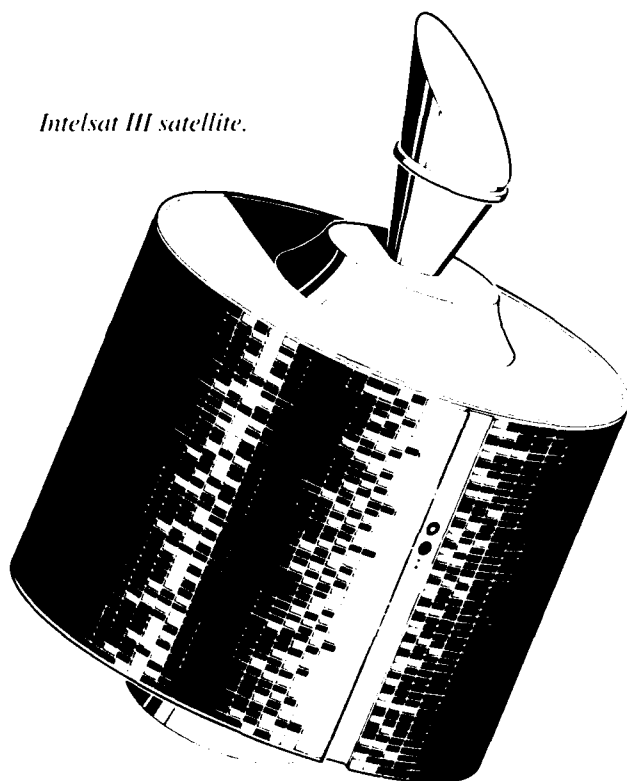
The first Intelsat II satellite (IIA) was launched in October 1966; but, because of an apogee motor malfunction, its final orbit was elliptical with a synchronous altitude apogee. It was used for communications in the Pacific area a few hours a day until Satellite IIB was launched. After that, it was used occasionally for ground station tests. Satellites IIB, IIC, and IID were launched successfully and operated properly. They were used both in regular commercial service and in the NASA communications network. These three satellites, along with Early Bird, were retired by 1971.

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INTELSAT III

Intelsat III satellite.



Work on the Intelsat III satellites [1-7] started in 1966 about the time the first Intelsat II was launched. The objective of the Intelsat III program was to develop satellites, with greater capacity than the previous satellites, which had a multiple access capability allowing communications between any pair of terminals within view of the satellite. The Intelsat III program was the first to provide global service, with satellites serving each of the three ocean areas of the world. This fulfilled a goal defined in the original charter of the Intelsat organization.

The Intelsat III satellites were larger than the Intelsat II satellites. The basic design was similar, with equipment mounted on a platform within a spinning, cylindrical body on which solar cells were mounted. A despun antenna was the major new feature of the Intelsat III design. The beamwidth of the antenna was opti-

mized for earth coverage and provided significantly more gain than the antennas on earlier satellites. Increased gain was the major reason the Intelsat III communication capacity was five times that of Intelsat II. The communication subsystem had two independent repeaters, each with a bandwidth of 225 MHz. The satellite details are as follows:

Satellite

Cylinder, 56-in. dia., 41-in. height (78 in. overall)

Approximately 330 lb in orbit, beginning of life

Solar cells and NiCd batteries, 160 W at beginning of life, 130 W minimum after five years

Spin-stabilized, 90 rpm

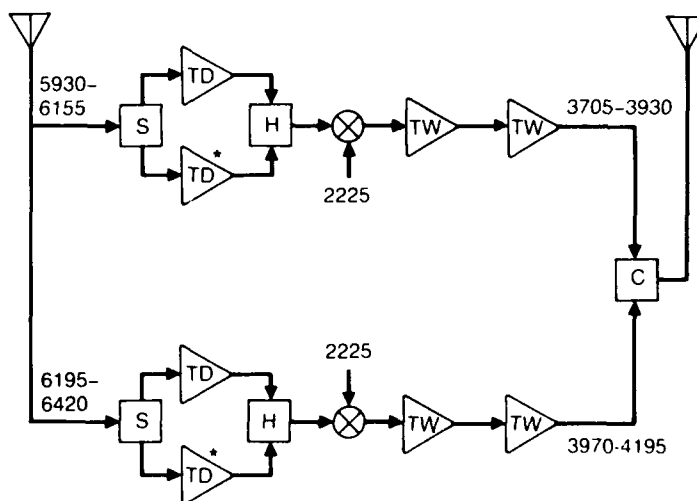
Solid rocket motor for apogee maneuver, hydrazine monopropellant for on-orbit use

Configuration

Two 225-MHz bandwidth single-conversion repeaters

Capacity

1200 two-way voice circuits or four TV circuits



* Spare TD and switching not in first 3 satellites

Intelsat III communication subsystem.

Transmitter

3705 to 3930 MHz and 3970 to 4195 MHz

Each repeater has a low-level TWT driving a high-level TWT 10-W output, 27-dBW ERP each repeater (22-dBW minimum at edge of earth)

Receiver

5930 to 6155 MHz and 6195 to 6420 MHz

Two tunnel diode amplifiers in each repeater (one on, one standby) (standby amplifiers not on first three satellites)

<7-dB noise figure

Antenna

Despun conical horn with flat reflector 45 deg to horn axis

19.3-deg beamwidth, circular polarization

Transmit: 18-dB peak gain

Receive: 21-dB peak gain

Design life

Five years

Orbit

Synchronous equatorial

Orbital history

Satellite, launch date, service area, and comments. (Dates in parentheses indicate end of active service. The Intelsat III satellites are no longer available for service.):

IIIA, 18 September 1968, failed to achieve proper orbit

IIIB, 18 December 1968, Atlantic (March 1970)

IIIC, 5 February 1969, Pacific, Indian (April 1979)

IIID, 21 May 1969, Pacific (November 1972)

IIIE, 25 July 1969, failed to achieve proper orbit, reentered the atmosphere 14 October 1988

IIIF, 14 January 1970, Atlantic (March 1972), Indian, Pacific, December 1974)

IIIG, 22 April 1970, Atlantic (failed in March 1972)

IIIH, 23 July 1970, failed to achieve proper orbit

Delta launch vehicle

Management

Developed by TRW Systems Group (6% subcontracted in Western Europe and Japan) for Comsat Corporation/Intelsat

Operated by Comsat Corporation for Intelsat

Originally, the Intelsat III program was to include six launches. During the course of the program, however, partially because of the failure of the first launch, the program was extended to eight launches. The seventh satellite was fabricated from available spare parts, and the eighth was the refurbished prototype. Between December 1968 and April 1970, five of the eight satellites were successfully placed into synchronous orbit, and all five operated satisfactorily. A component failure reduced the capacity of Intelsat IIIC, but it was moved from the Pacific to the Indian Ocean area, where it provided acceptable service in view of the lower traffic density. Beginning in 1972, the Intelsat III satellites were removed from service as the Intelsat IV satellites became available.

* * * * *

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INTELSAT IV

The Intelsat III satellites were a significant improvement over the previous Intelsat satellites. However, prior to the first Intelsat III launch, it was recognized that the continually increasing demand for communication satellite services would shortly require even larger satellites in orbit. Therefore, design work was begun on Intelsat IV [1-7] about the time the first Intelsat III satellites were brought into service. The main requirements for the Intelsat IV satellites were to provide increased capacity and operational flexibility while remaining compatible with existing ground terminals.

The design of Intelsat IV differed significantly from that of Intelsat III and was based on the Tactical Communications Satellite (Tacsat) design. The antennas and communications electronics were all mounted on a platform that was despun relative to the main body of the satellite in order to remain pointed at the earth. All other equipment were mounted within the large cylindrical satellite body, which spun to provide stabilization. Like Tacsat,

but unlike other previous satellites, the spin axis was not the axis of the maximum moment of inertia, and special attitude control devices were required to maintain stability. The Intelsat IV solar array was much larger than that of Intelsat III, thereby allowing a significant increase in total transmitter power. Additional details are as follows:

Satellite

Cylinder, 94-in. dia., 111-in. height [210 in. (17.5 ft) overall]

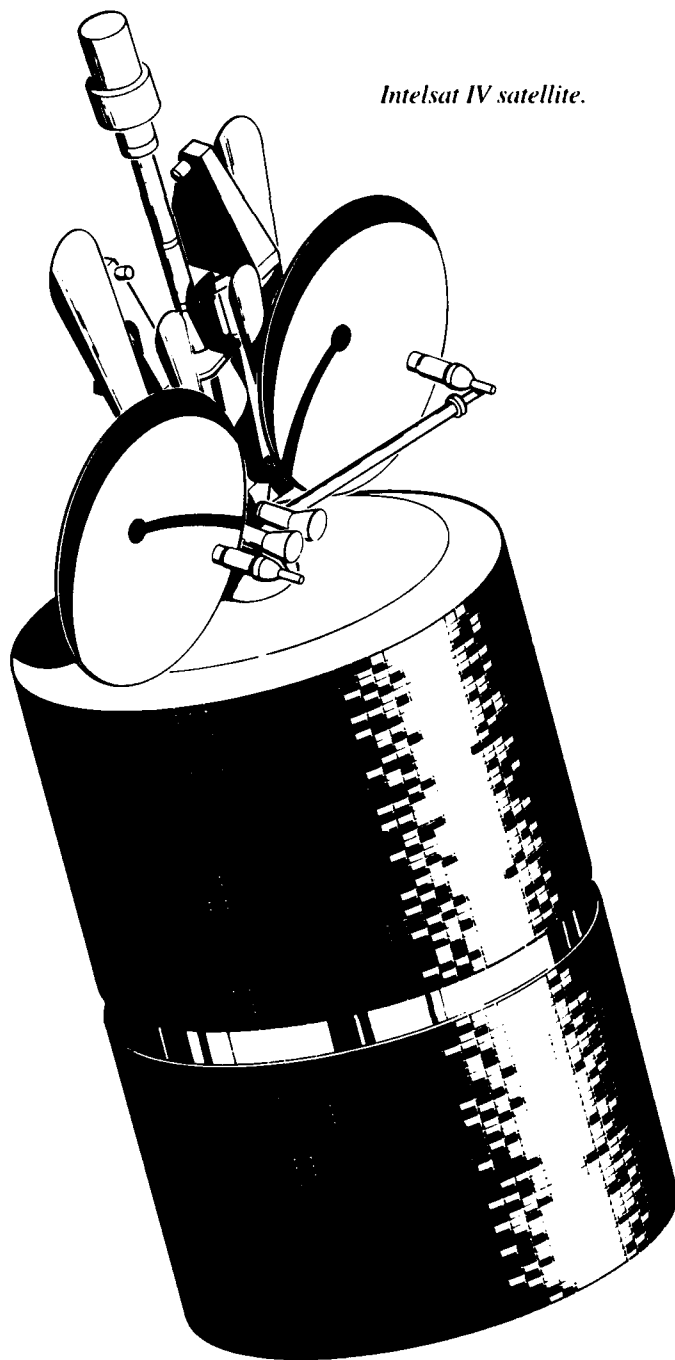
Approximately 1600 lb in orbit, beginning of life

Solar cells and NiCd batteries, 570 W initially, 460 W at end of life

Spin-stabilized, gyrost, 50 to 60 rpm, antenna pointing error $< \pm 0.35$ deg (each axis)

Solid rocket motor for apogee maneuver, hydrazine monopropellant for on-orbit use

Intelsat IV satellite.



Configuration

Twelve 36-MHz bandwidth single-conversion repeaters

Capacity

Total of 3000 to 9000 two-way telephone circuits depending on use of earth coverage or narrowbeam antennas, number of carriers per repeater, and modulation formats

One color TV channel per repeater

Transmitter

3707 to 4193 MHz

Two TWTs per repeater (one on, one standby)

6-W output per repeater

ERP per repeater: 22.0 dBW (earth coverage antenna), 33.7 dBW (narrowbeam antenna), both at -3 dB points of antenna pattern

Receiver

5932 to 6418 MHz

Four complete units (one on, three standby), tunnel diode preamplifiers

8.2-dB noise figure

G/T: -18.7 dB/K minimum, -17.2 dB/K nominal

Antenna

Four earth coverage horns, 20.5-dB gain, 17-deg beamwidth (two for transmit and two for receive)

Two narrowbeam parabolas, 50-in. dia., 31.7-dB gain, 4.5-deg beamwidth, steerable in the 17-deg earth coverage cone

All six antennas mounted on a despun platform and circularly polarized

Design life

Seven years

Orbit

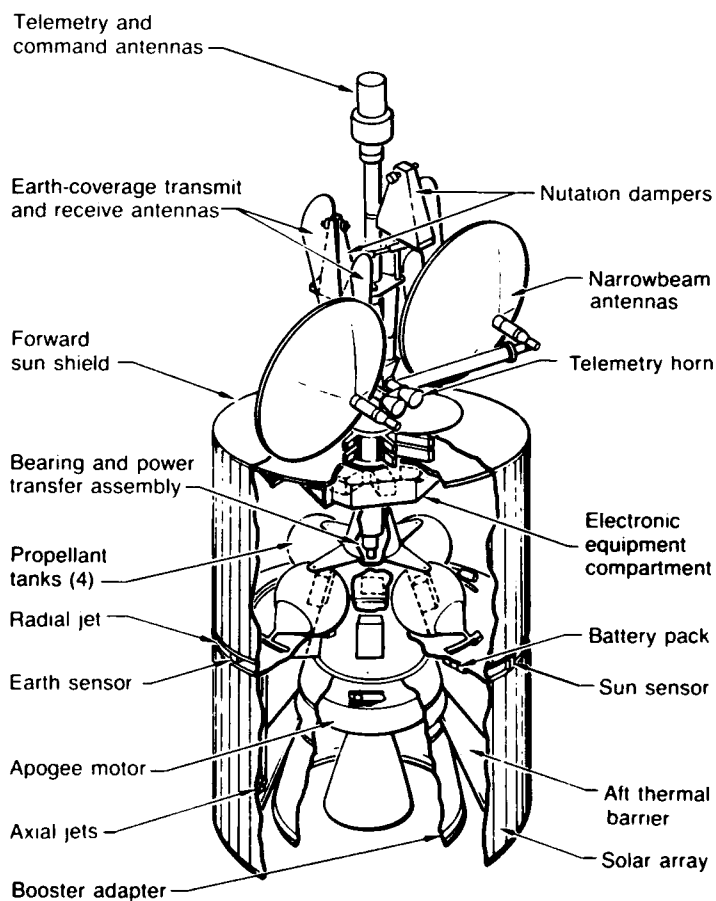
Synchronous equatorial, stationkeeping to $\pm 0.1^\circ$ N-S and E-W

Orbital history

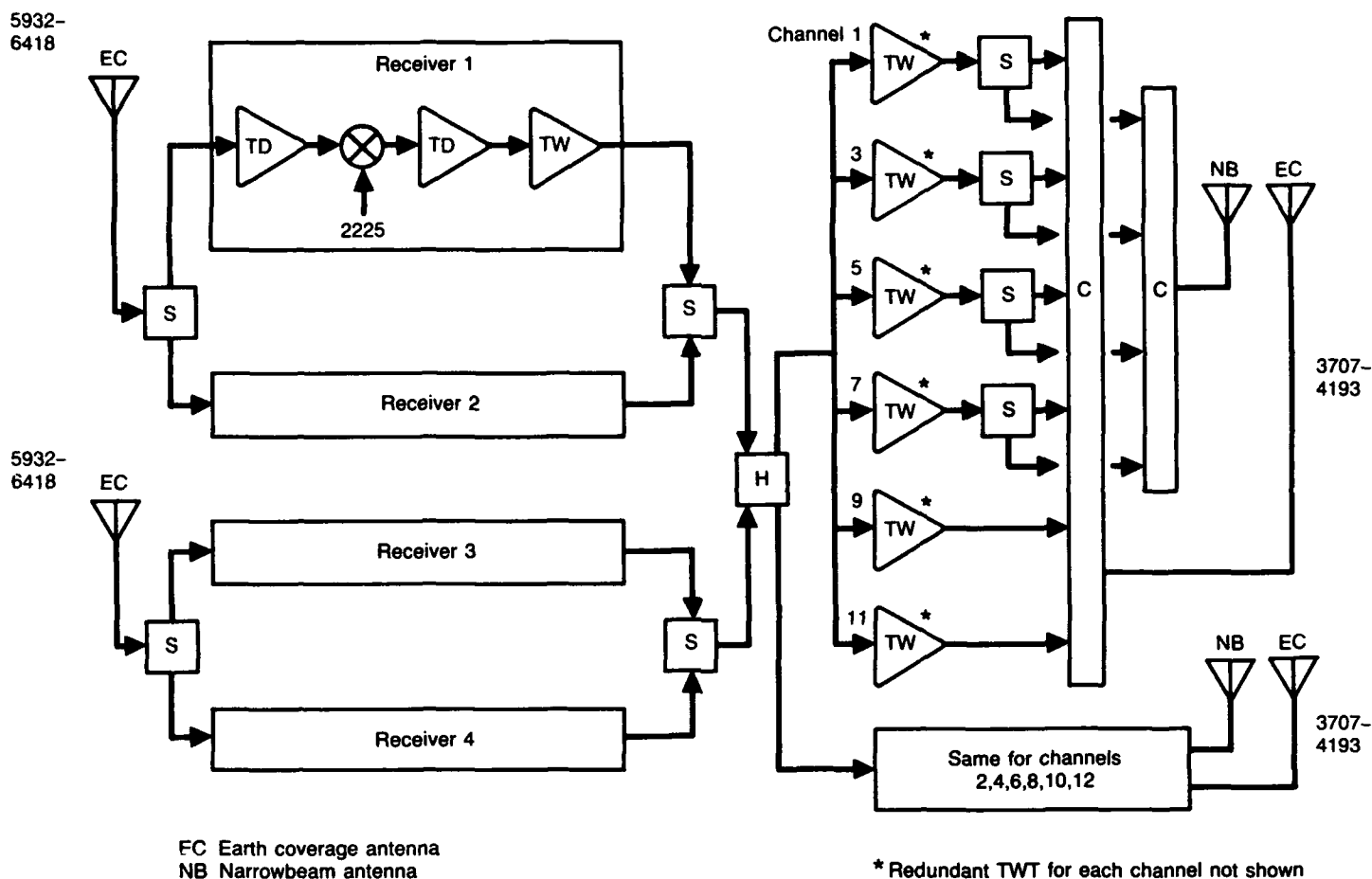
Satellite, launch date, service area, and comments:

F-2, 25 January 1971, service life about nine years, then moved above synchronous orbit

F-3, 19 December 1971, service life about 10 years, then moved above synchronous orbit



Intelsat IV satellite details.



Intelsat IV communication subsystem.

F-4, 23 January 1972, service life about 11 years, then moved above synchronous orbit

F-5, 13 June 1972, service life about nine years, then moved above synchronous orbit

F-7, 23 August 1973, service life about 11 years, then moved above synchronous orbit

F-8, 21 November 1974, service life about 10 years, then moved above synchronous orbit

F-6, 20 February 1975, launch vehicle failure

F-1, 22 May 1975, service life about 12 years, then moved above synchronous orbit

Atlas-Centaur launch vehicle

Management

Developed by Hughes Aircraft Company for Comsat Corporation/Intelsat, approximately 20% subcontracted to companies in Western Europe, Japan, and Canada

Operated by Intelsat

Previous Intelsat satellites all had one or two communication channels; with each new design, increased capacity was achieved by increasing the channel bandwidth. The resulting capacity was always limited by the available transmitter power. Since the Intelsat III design used 450 MHz of the 500-MHz allocation, the Intelsat IV design was bandwidth-limited, and 12 separate repeaters were used to achieve more efficient spectrum utilization. The total repeater bandwidth was 432 MHz, but the total capacity using

earth coverage antennas was 3000 telephone circuits—2.5 times the capacity of Intelsat III.

Intelsat IV was the first satellite to have narrowbeam antennas. It had two transmitting antennas with 4.5-deg beamwidths in addition to the earth coverage (approximately 17-deg beamwidth) receiving and transmitting antennas. Up to four repeaters were connected to each narrowbeam antenna, providing a maximum satellite capacity of 9000 telephone circuits. Under normal operating conditions, each Intelsat IV provided a capacity of 4000 to 6000 circuits. The maximum capacity was not realized because of the inefficiencies incurred when several transmissions shared a repeater.

All eight Intelsat IV satellites have been launched, with only one unsuccessful launch. The first launch was in January 1971 and the last in May 1975. All the satellites, except for one lost in a launch failure, had service lives of 9 to 12 years. Generally, the service life began with a period of active service, followed by a period as a spare or used for leased service. All have been turned off and moved above synchronous orbit, the last in 1987, so that they cannot interfere with active satellites.

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INTELSAT IV-A

The North Atlantic area has always had the largest volume of communications traffic and is the area that paces the introduction of higher capacity satellites into the Intelsat system. By 1972, two Intelsat IV satellites operating together were required in this area. According to the projections of capacity demand, these two satellites would have been saturated by the end of 1975. Providing more capacity would require either a third Intelsat IV or a new satellite of larger capacity. Since the first alternative would force several ground stations to construct another antenna, Intelsat elected to develop Intelsat IV-A [1-10].

The support subsystems and satellite body of Intelsat IV-A are the same as for Intelsat IV except for more efficient solar cells. It has five communication antennas: global coverage receive, global coverage transmit, spot beam receive, and two spot beam transmit. The new antennas and communication electronics allow an increase to twenty 36-MHz channels from the twelve on Intelsat IV. The satellite details are as follows:

Satellite

Cylinder, 94-in. dia., 111-in. height [275 in. (23 ft) overall]

1820 lb in orbit, beginning of life

Solar cells and NiCd batteries, 590 W at beginning of life, 525 W at end of life

Spin-stabilized, gyrostad, approximately 50 rpm, antenna pointing error $\leq \pm 0.25^\circ$ (N-S axis) and $\leq \pm 0.2^\circ$ (E-W axis)

Solid rocket motor for apogee maneuver, hydrazine monopropellant for on-orbit use

Configuration

Twenty 36-MHz bandwidth single-conversion repeaters, dual beam frequency reuse

Capacity

Maximum capacity approximately 15,000 two-way voice circuits; nominal capacity in a typical operational configuration is approximately 6000 two-way voice circuits plus two transponders for SPADE and TV transmissions

Transmitter

3707 to 4193 MHz

Two 6-W TWTs (one on, one standby) for each of the four global coverage channels

One 5-W TWT for each of the 16 spot-beam channels, with one spare TWT for every two channels

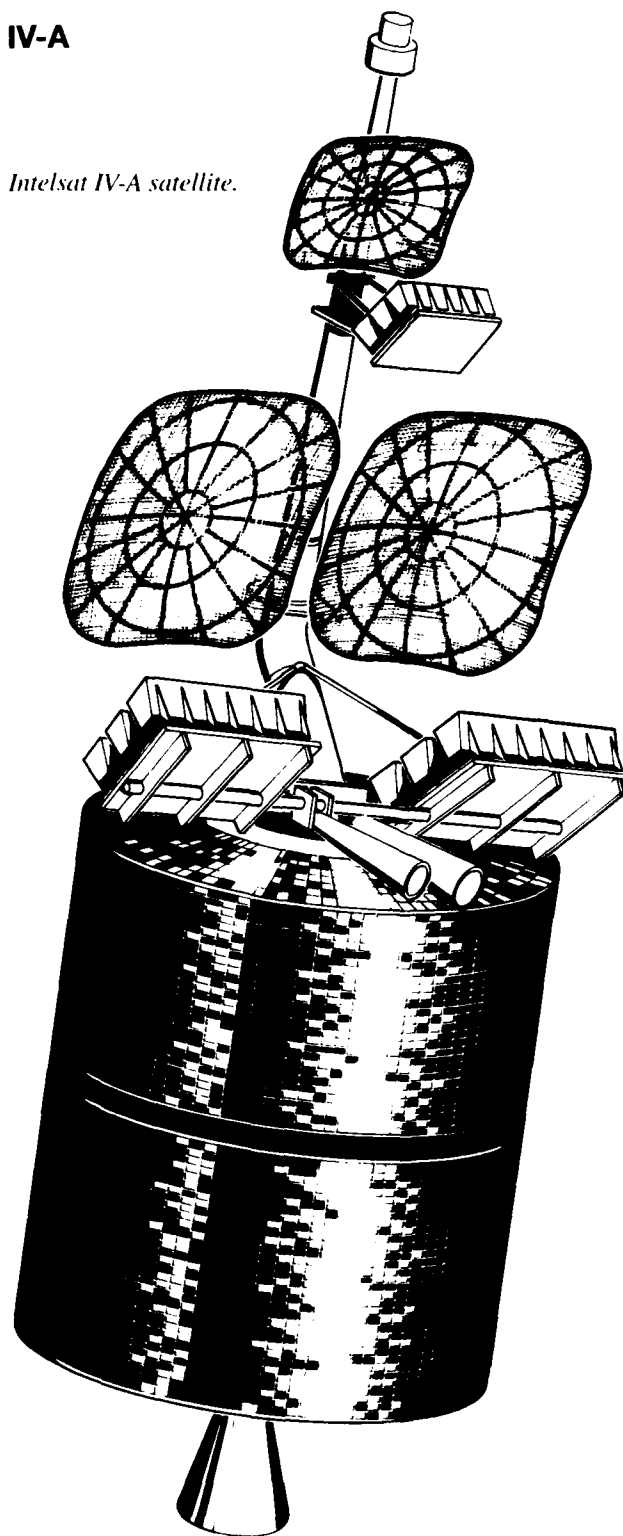
Minimum ERP per repeater at edge of coverage 29 dBW (spot beam), 26 dBW (hemispheric beam), 22 dBW (global beam)

Receiver

5932 to 6418 MHz

Four hemispheric beam receivers (two on, two standby)

Intelsat IV-A satellite.



Two global beam receivers (one on, one standby)
 8-dB noise figure, -11.6 dB/K G/T (hemispheric beam), -17.6 dB/K G/T (global beam)

Antenna

Two earth coverage horns (one transmit, one receive)

Three spot-beam antennas with multiple feeds to generate coverage patterns approximating continental shapes (two transmit, one receive); at least 27-dB isolation between eastern and western lobes of each antenna; each antenna is approximately square except for rounded corners, 54 in. across for transmit, 35 in. for receive

All antennas mounted on a despan platform and circularly polarized

Design life

Seven years

Orbit

Synchronous equatorial, stationkeeping to $\pm 0.1^\circ$ N-S and E-W

Orbital history

Satellite, launch date, service area, and comments:

F-1, 25 September 1975, service life exceeded design life, then moved above synchronous orbit

F-2, 29 January 1976, service life exceeded design life, then moved above synchronous orbit

F-4, 26 May 1977, service life exceeded design life, then moved above synchronous orbit

F-5, 29 September 1977, launch vehicle failure

F-3, 6 January 1978, service life exceeded design life, then moved above synchronous orbit

F-6, 31 March 1978, service life exceeded design life, then moved above synchronous orbit

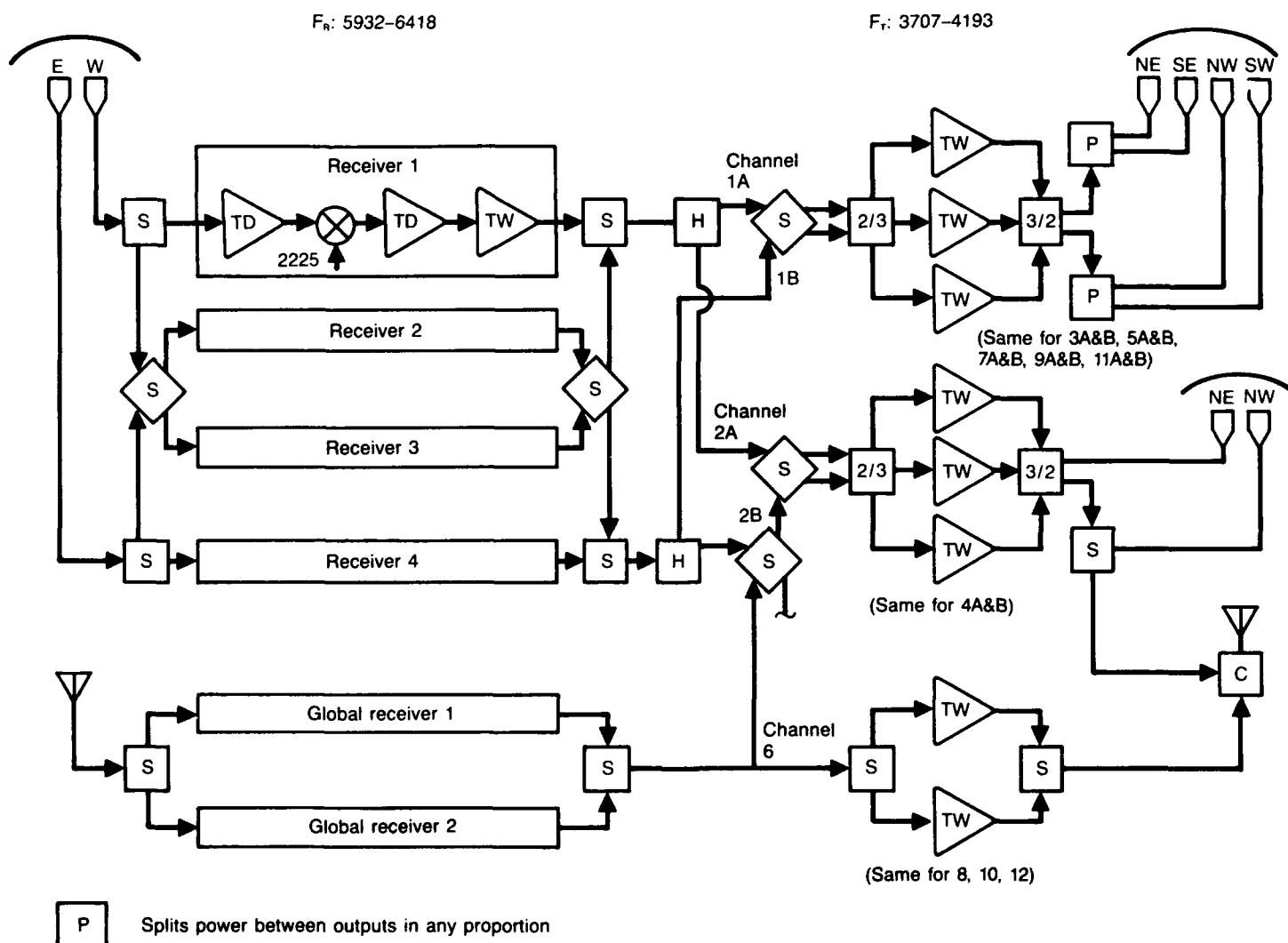
Atlas-Centaur launch vehicle

Management

Developed by Hughes Aircraft Company and subcontractors in Western Europe, Japan, and Canada for Comsat Corporation/Intelsat

Operated by Intelsat

Four of the twenty channels on Intelsat IV-A are devoted to global coverage. All four channels pass through one of the redundant global coverage receivers. Each channel has redundant 6-W TWTs. Sixteen channels are connected to the spot-beam antennas



Intelsat IV-A communication subsystem.

and are divided into A and B groups, each with eight channels. All the channels within a group use separate frequencies, but the corresponding channels of the two groups (e.g., 1A and 1B) use the same frequencies. There are four receivers for these channels, but only two are used at a time (one for each group). The spot-beam channels use 5-W TWTs, with one spare TWT available for every two channels.

The spot-beam antennas have east and west beams to prevent interference between overlapping channels; the A channel of each pair uses one beam, and the B channel uses the other beam. The satellites are positioned over oceans, with the spot beams serving the continental areas on either side of the ocean. (Any terminals near the satellite longitude are between the two beams and must use the global coverage channels.) There is at least 27-dB isolation between the two beams. The receive antenna has two sets of feed horns that produce the two beams (east and west). One transmit antenna has four sets of feed horns that produce northeast, northwest, southwest, and southeast beams. The eastern pair of beams is isolated from the western pair, but the north and south members of a pair are not isolated, since they carry no overlapping channels. Six channels are connected to the west beams of this antenna and six to the east beams. Each of the channels connected to the east side may have its power split in any proportion between the northeast and southeast beams and similarly for channels connected to the west side. The other transmit antenna has two sets of feed horns that produce northeast and northwest beams, and two channels are connected to each of these beams. In an optional mode, two of these channels may be switched to a global coverage antenna, in which case the other two must be turned off. A considerable number of switches in the communication subsystem allow great flexibility in routing signals, subject only to the constraint that the A and B channels of any one pair are not simultaneously on the same beam.

Each beam on both the receive and transmit antennas is formed by a set of feed horns that shapes the beams for coverage of the proper land masses. The coverage being used is adequate for Atlantic, Pacific, and Indian Ocean areas with fixed feed horns and fixed reflectors, with only one exception. This fact simplifies the satellites, since no antenna gimbaling is required; it also allows the flexibility to move a satellite from one ocean area to another. The exception to the general coverage is an additional feed horn that must be switched into the west receive beam and south-

west transmit beam to provide adequate coverage of New Zealand and from an Intelsat IV-A in the Pacific region.

At first, three Intelsat IV-A satellites were ordered, followed by a second order for three more in 1974. All six were launched between September 1975 and March 1978. The first three were placed into service in the Atlantic region; they were turned off and moved above synchronous orbit in the mid-1980s. The fourth was lost as the result of a launch vehicle failure. The last two were in the Indian Ocean region for several years, then moved to the Pacific region when replaced by two Intelsat V satellites. They were in use until 1989.

* * * * *

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INTELSAT V

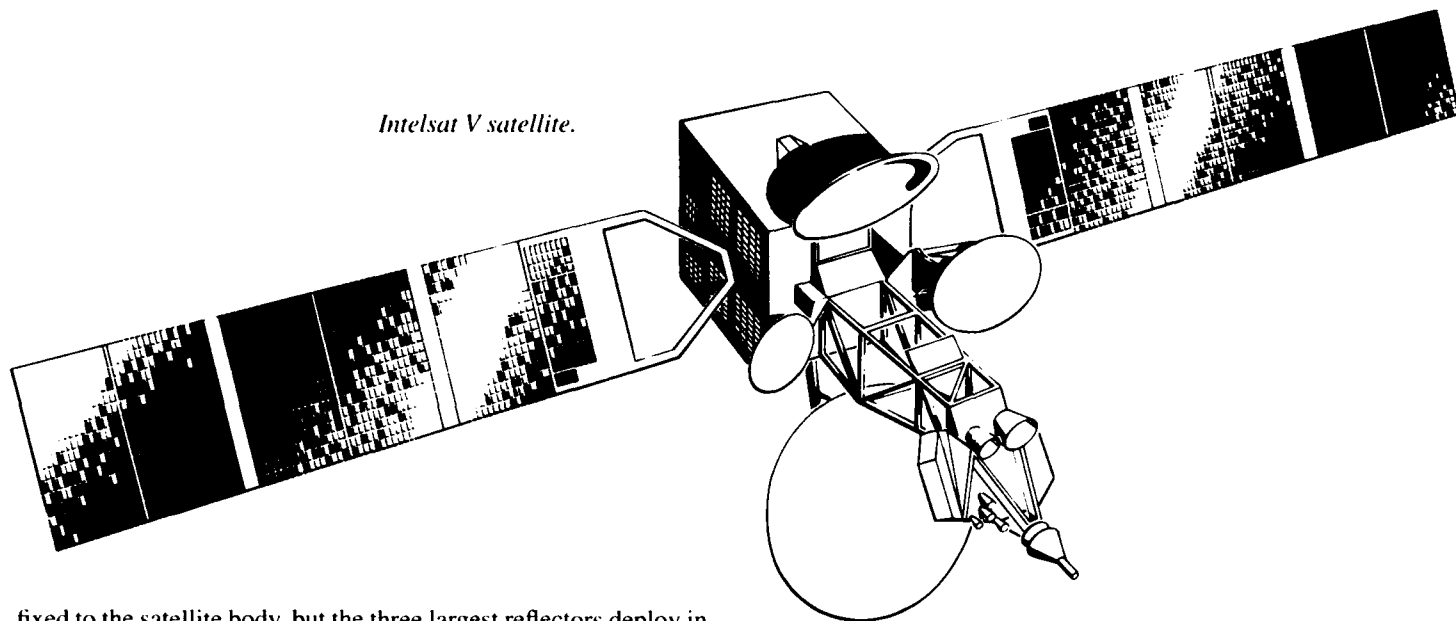
Forecasts of Intelsat traffic project steady increases and, consequently, new model satellites must be introduced into the system at intervals of about four to five years. The Intelsat IV-A satellites were first used in 1975. These satellites provided a moderate capacity increase without requiring significant ground terminal changes. However, further capacity increases were not practical with a simple stretching of the Intelsat IV/IV-A design, so development of a new satellite was begun in 1976. The new satellite (Intelsat V) is in use in all three ocean regions.

The Intelsat V satellites [1-21] have two new design features that require significant ground terminal changes. The first feature is the use of dual-polarization uplinks and downlinks in the 4- and 6-GHz bands. All previous Intelsat satellites used one polarization for uplinks and the orthogonal polarization for downlinks. This change requires improvements at all ground terminals to en-

sure isolation between the two polarizations. The dual polarizations are combined with the two independent beams (east and west) introduced on Intelsat IV-A. Together, these techniques triple the satellite capacity in the 4- and 6-GHz bands, compared with the Intelsat IV design. The second new feature is the use of the 11- and 14-GHz bands, and two independent beams are used with these bands also. The nations with the largest traffic volumes will use these new frequencies and must construct new terminals for them.

The Intelsat V satellites have a rectangular body about 6 ft across. The sun-tracking solar arrays, composed of three panels each, are deployed in orbit. On the earth-viewing face of the body is an antenna tower on which are mounted both the communications and telemetry, tracking, and command (TT&C) antennas and the feed networks for the large reflectors. The tower is

Intelsat V satellite.



fixed to the satellite body, but the three largest reflectors deploy in orbit. The tower is about 15 ft tall and is constructed almost entirely of graphite fiber/epoxy materials for strength, light weight, and thermal stability. The entire satellite weighs about 2200 lb in orbit and spans about 51 ft across the solar arrays.

The communication subsystem operates at the 4- and 6-GHz frequencies used by all previous Intelsat satellites as well as at 11 and 14 GHz. The 4- and 6-GHz bands have twenty-one transponders, sixteen with 72- or 77-MHz bandwidths and five with 36- or 41-MHz bandwidths. The sixteen wider transponders are operated with fourfold frequency reuse; there are four separate frequencies, each with four transponders. Within each co-frequency set, two transponders are assigned to west beams and two to east beams. Thus, these transponder pairs are kept independent by the angular separation of the beams—the same technique used on Intelsat IV-A. The pairs that share a common frequency and direction are kept independent by the assignment of one to a hemispheric beam and one to a smaller zone beam. These beams are separated, not by direction, but by orthogonal polarizations. Of the five narrower transponders, two use the east and west beams for twofold frequency reuse and the other three are global beams. The pair of narrow reuse transponders and/or one pair of hemispheric beam reuse transponders can be switched to use one of each pair for additional global service with the other turned off. For all of the reuse transponders, several possible transmit and receive connections are possible, as shown in the communication subsystem block diagram.

The 11- and 14-GHz bands have six transponders, two each of 72-, 77-, and 241-MHz bandwidths. They are used in twofold frequency reuse through east and west spot beams. These transponders may be operated only at 11 and 14 GHz or may be cross connected with the other frequencies. For example, one transponder may be switched to 14-GHz receive and 4-GHz transmit and another to 6-GHz receive and 11-GHz transmit. The 4- and 6-GHz signals pass through the satellite with a single frequency conversion, whereas all 11- and 14-GHz signals use a 4-GHz intermediate frequency so that all interconnections can be done at a common frequency.

The 4/6-GHz hemispheric and zone beams are formed by one transmit and one receive antenna. Each is composed of a parabolic reflector and an 88-horn feed. These beams are not steerable, but there are switches in the zone beam feed matrices, because the pattern required for the satellite serving the Indian Ocean is different from that required for the Atlantic and Pacific regions. The

11/14-GHz spot beams are formed by parabolic reflectors that are each steerable over a limited portion of the Northern Hemisphere.

The initial Intelsat V contract was for seven satellites; later an eighth and then a ninth were added to the contract. (The satellites called Intelsat V F-10 to F-15 are the Intelsat V-A series.) The first launch was in December 1980; the last, the only failure, in 1985. The eight satellites successfully launched have operated properly and all were still in use at the end of 1990. The Intelsat V characteristics are summarized as follows:

Satellite

Rectangular body $5.4 \times 5.8 \times 6.6$ ft, 51 ft across tips of deployed solar arrays, 21.7-ft height to top of antenna tower

Approximately 2280 lb in orbit, beginning of life; approximately 1820 lb end of life (satellites with the maritime subsystem are about 80 lb more)

Sun-tracking solar arrays and NiCd (NiH₂ for F-5 to F-9) batteries, approximately 1800 W beginning of life, 1290 W minimum after seven years

Three-axis stabilization using momentum wheels, antenna pointing accuracy ± 0.2 deg in pitch and roll, ± 0.5 deg in yaw

Solid rocket motor for apogee maneuver, hydrazine monopropellant for on-orbit use

Configuration

4/6 GHz: twenty-one single-conversion repeaters with bandwidths of 36 to 77 MHz, dual-beam and dual-polarization frequency reuse

11/14 GHz: six double-conversion repeaters with bandwidths of 72 to 241 MHz, dual-beam frequency reuse

Capacity

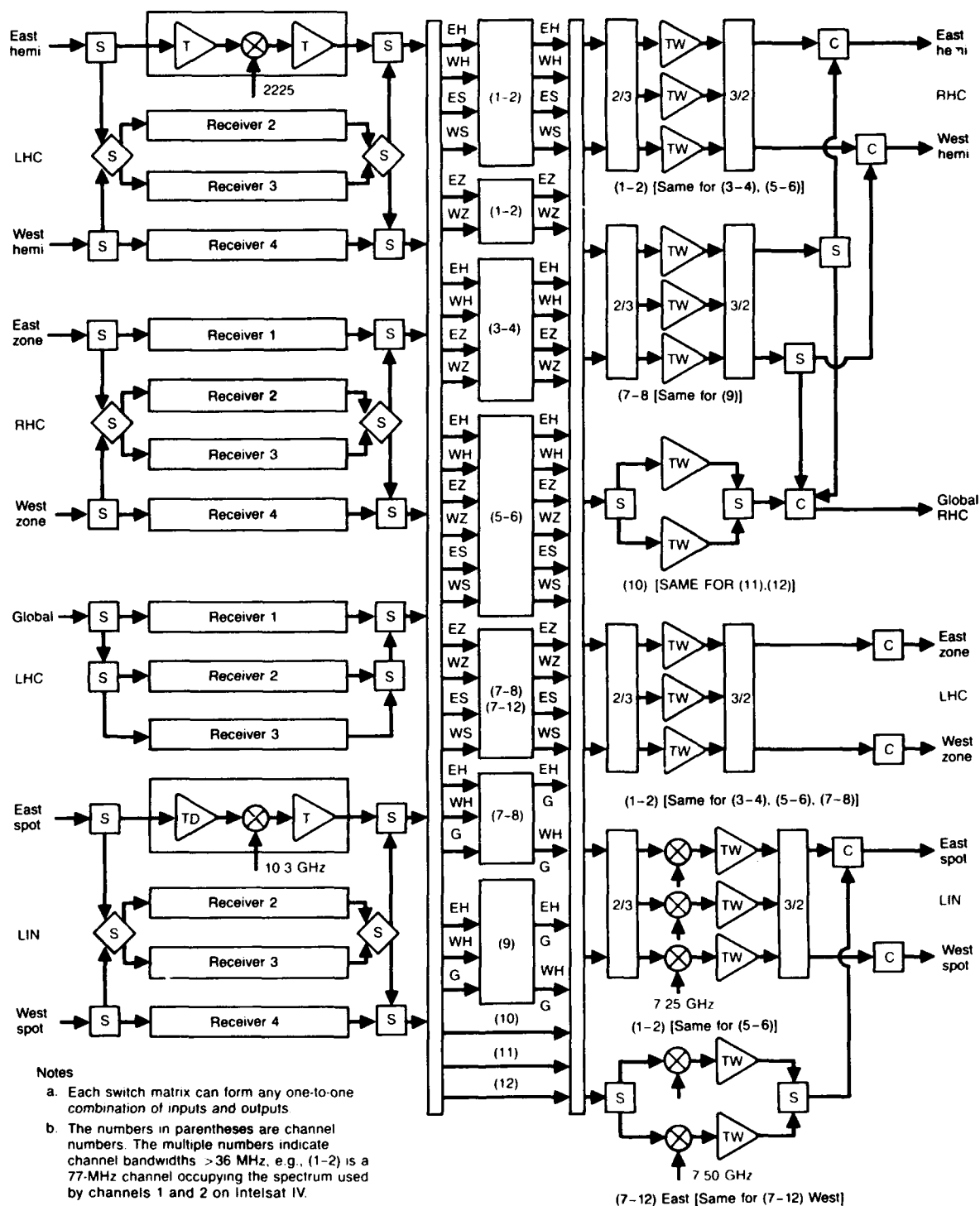
Nominal capacity in a typical operation configuration is 12,000 two-way voice circuits plus two TV transmissions

Transmitter

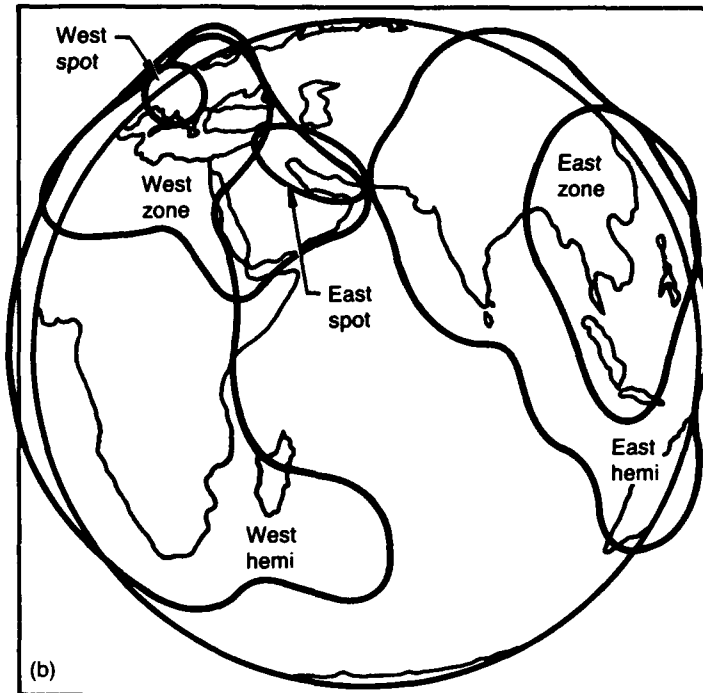
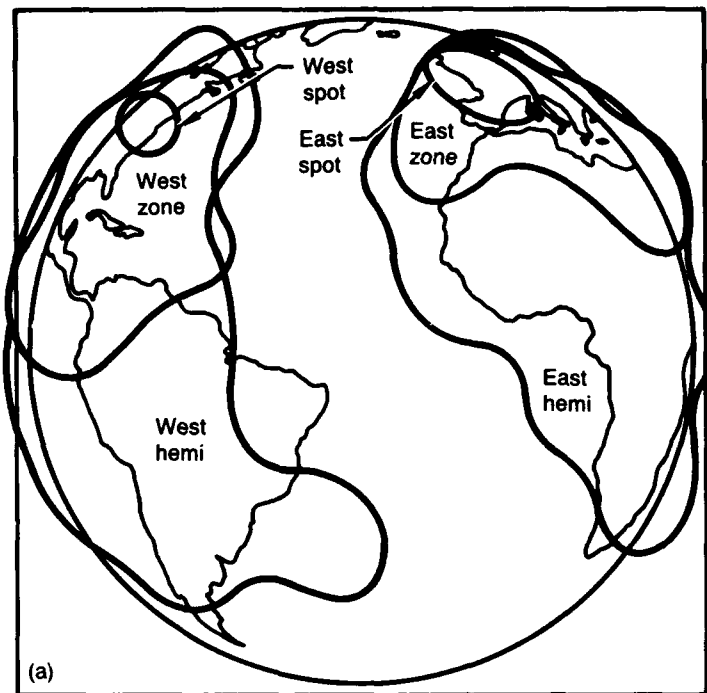
4/6 GHz: 3704 to 4198 MHz

Global beam: one 8.5-W TWT per repeater plus one spare per repeater

Hemispheric beam: one 8.5-W TWT per repeater plus one spare per two repeaters



Intelsat V communication subsystem.



Intelsat V antenna patterns. (a) Atlantic Ocean; (b) Indian Ocean.

Zone beam: one 4.5-W TWT per repeater plus one spare per two repeaters

ERP (specified minimum): 23.5 dBW (global beam); 26 dBW (hemispheric or zone beam, 36-MHz repeaters); 29 dBW (hemispheric or zone beam, 72- to 77-MHz repeaters)

11/14 GHz: 10.954 to 11.191 GHz, and 11.459 to 11.698 GHz

One 10-W TWT per repeater (one for one redundancy for 241-MHz repeaters, one for two redundancy for 72- to 77-MHz repeaters)

ERP (specified minimums): 41.1 dBW (east spot), 44.4 dBW (west spot)

Receiver

4/6 GHz: 5929 to 6423 MHz

Five active receivers with six spares, bipolar preamplifiers (F-1 to F-4), FET preamplifiers (F-5 to F-9)

G/T: -18.6 dB/K (global beam), -11.6 dB/K (hemispheric beam), -8.6 dB/K (zone beam), all minimum values (all improve 2.6 dB for F-5 to F-9).

11/14 GHz: 14.004 to 14.498 GHz

Two active receivers with two spares, tunnel diode preamplifiers (F-1 to F-6), FET preamplifiers (F-7 to F-9)

G/T: 0.0 dB/K (east spot), +3.3 dB/K (west spot), both minimum values

Antenna

4/6 GHz: two earth coverage horns (one transmit, one receive); 18-deg/22-deg beamwidths, 16.5-dB/14.5-dB minimum gains; two reflectors (96-in. dia. transmit, 61-in. dia. receive), each with 88-horn feeds, each generating two hemispheric beams (21.5-dB minimum gain) and two smaller zone beams (24.5-dB minimum gain); zone beams each overlap a portion of one of the hemispheric beams and are separated by orthogonal polarizations; beam shapes are optimized to cover specified terminal locations; circular polarization; minimum interbeam spatial or polarization isolation 27 dB

11/14 GHz: two reflectors (one east, one west), each generating one beam for transmission and reception; west beam is 1.6 deg with minimum gain of 36 dB, east beam is 1.8 deg \times 3.2 deg with minimum gain of 33 dB; each beam steerable over a limited portion of the earth; linear polarization; minimum interbeam spatial isolation 33 dB

Design life

Ten years

Orbit

Synchronous equatorial, stationkeeping to $\pm 0.1^\circ$ N-S and E-W

Orbital history

Satellite, launch date, service area, and comments:

F-2, 11 December 1980, Atlantic, 22° W longitude

F-1, 23 May 1981, Pacific, 177° E longitude

F-3, 15 December 1981, Pacific, 177° E longitude

F-4, 5 March 1982, Atlantic, 34.5° W longitude

F-5, 28 September 1982, Indian, 66° E longitude

F-6, 19 May 1983, Atlantic, 18.5° W longitude

F-7, 19 October 1983, moved out of synchronous orbit in 1990

F-8, 4 March 1984, Pacific, 180° W longitude

F-9, launch vehicle failure, June 1985, left satellite in low orbit, from which it decayed October 1985

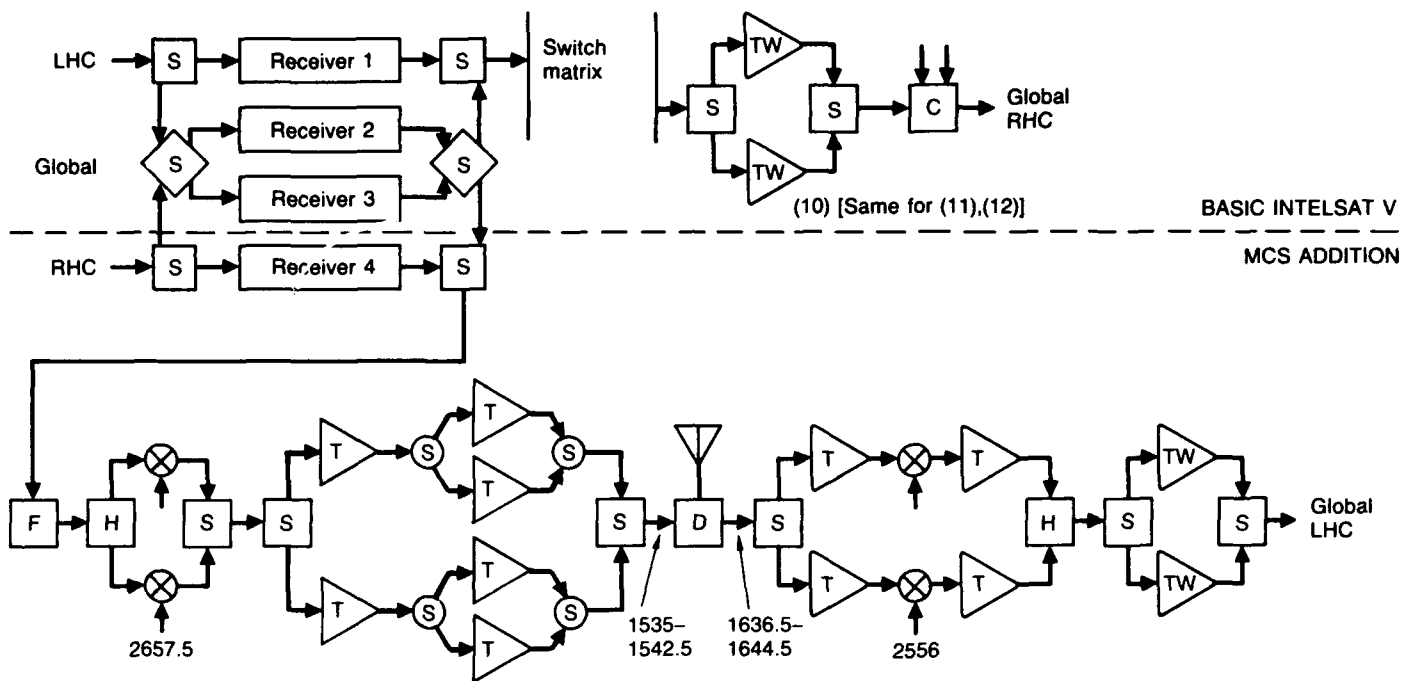
Atlas-Centaur launch vehicle (F-1 to F-6, F-9)

Ariane launch vehicle (F-7 to F-8)

Management

Developed by Ford Aerospace and Communications Corporation for Comsat Corporation/Intelsat, approximately 23% subcontracted to companies in France, West Germany, United Kingdom, Japan, and Canada

Operated by Intelsat



Intelsat V maritime communication subsystem.

In mid-1978, Intelsat began a detailed study of the addition of a maritime communication subsystem (MCS) to some of the Intelsat V satellites. This subsystem has been developed for use as part of the Inmarsat system space segment. It was added to Satellite 5 launched in September 1982 and also Satellites 6 through 9.

The maritime subsystem makes use of some of the global beam equipment of the basic communications payload. An L-band (1.5/1.6-GHz) antenna and some communications equipment have been added, as shown in the MCS block diagram. Several other modifications were added to the satellite beginning with the fifth flight model. These modifications were primarily to increase reliability and reduce weight, the latter partially compensating for the maritime subsystem addition. Because of power subsystem limitations, not all the maritime and 11-GHz capacity can be used simultaneously. This is acceptable to Intelsat, because the 11-GHz transponders are not expected to be used on all of the satellites. The maritime subsystem performance details are as follows:

Configuration

Coast to ship: one double conversion repeater with a 7.5-MHz bandwidth

Ship to coast: one single conversion repeater with an 8-MHz bandwidth

Capacity

Thirty voice circuits (high power mode) or fifteen voice circuits (low power mode)

Transmitter

L-band: 1535.0 to 1542.5 MHz; two transistor amplifiers (one active, one spare) 70- or 35-W output

ERP: ≥ 32.6 dBW at edge of coverage (high power mode) or ≥ 29.6 dBW (low power mode)

C-band: 4192.5 to 4200.5 MHz; two 4.5-W TWTs (one active, one spare)

ERP: 20 dBW at edge of coverage

Receiver

L-band: 1636.5 to 1644.5 MHz; two receivers (one active, one spare)

G/T: ≥ -15 dB/K

C-band: 6417.5 to 6425 MHz; four receivers (two active, two spare) shared with global coverage beam of basic payload

G/T: ≥ -17.6 dB/K

Antenna

L-band: one quad helix array, earth coverage, 14-dB gain at edge of coverage, 18-deg beamwidth, steerable $\pm 2^\circ$ E-W, circular polarization

C-band: uses earth coverage horns of the basic payload

* * * * *

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INTELSAT V-A

Intelsat V-A [1-4] is a modification of the Intelsat V design. Development started late in 1979. As with previous changes to Intelsat satellites, the primary goal is to increase satellite capacity to keep ahead of traffic growth in the Atlantic region.

Externally, the satellite appears almost identical to Intelsat V; internally, several changes were made to improve performance, reliability, and communications capacity. Several weight-saving measures were taken to compensate for the additional communications hardware. The internal arrangement of the communications hardware was modified for thermal balance. The satellite details given here are in many cases identical to those for Intelsat V. Intelsat V-A satellites do not have the MCS.

Satellite

Rectangular body 5.4 × 5.8 × 6.6 ft, 51 ft across tips of deployed solar arrays, 21.7-ft height to top of antenna tower

Approximately 2420 lb in orbit, beginning of life

Sun-tracking solar arrays and NiH₂ batteries, approximately 1800 W beginning of life, 1280 W minimum after seven years

Three-axis stabilization using momentum wheels, antenna pointing accuracy ±0.2 deg in pitch and roll, ±0.4 deg in yaw

Solid rocket motor for apogee maneuver, hydrazine monopropellant for on-orbit use

Configuration

4/6 GHz: twenty-six single-conversion repeaters with bandwidths of 36 to 77 MHz, dual-beam and dual-polarization frequency reuse

11/14 GHz: six double-conversion repeaters with bandwidths of 72 to 241 MHz, dual-beam frequency reuse

Capacity

Nominal capacity in a typical operation configuration is 15,000 two-way voice circuits plus two TV transmissions

Transmitter

4/6 GHz: 3704 to 4198 MHz

Global beam: one 8.5-W TWT per repeater plus one spare per repeater

Hemispheric beam: one 8.5-W TWT per repeater plus one spare per two repeaters

Zone beam: one 4.5-W TWT per repeater plus one spare per two repeaters

ERP (specified minimum): 23.5 dBW (global beam) (3 dB larger for Channel 7-8); 26 dBW (hemispheric or zone beam, 36-MHz repeaters); 29 dBW (hemispheric or zone beam, 72- to 77-MHz repeaters); 32.5 dBW (spot) (3 dB larger for Channel 7-8)

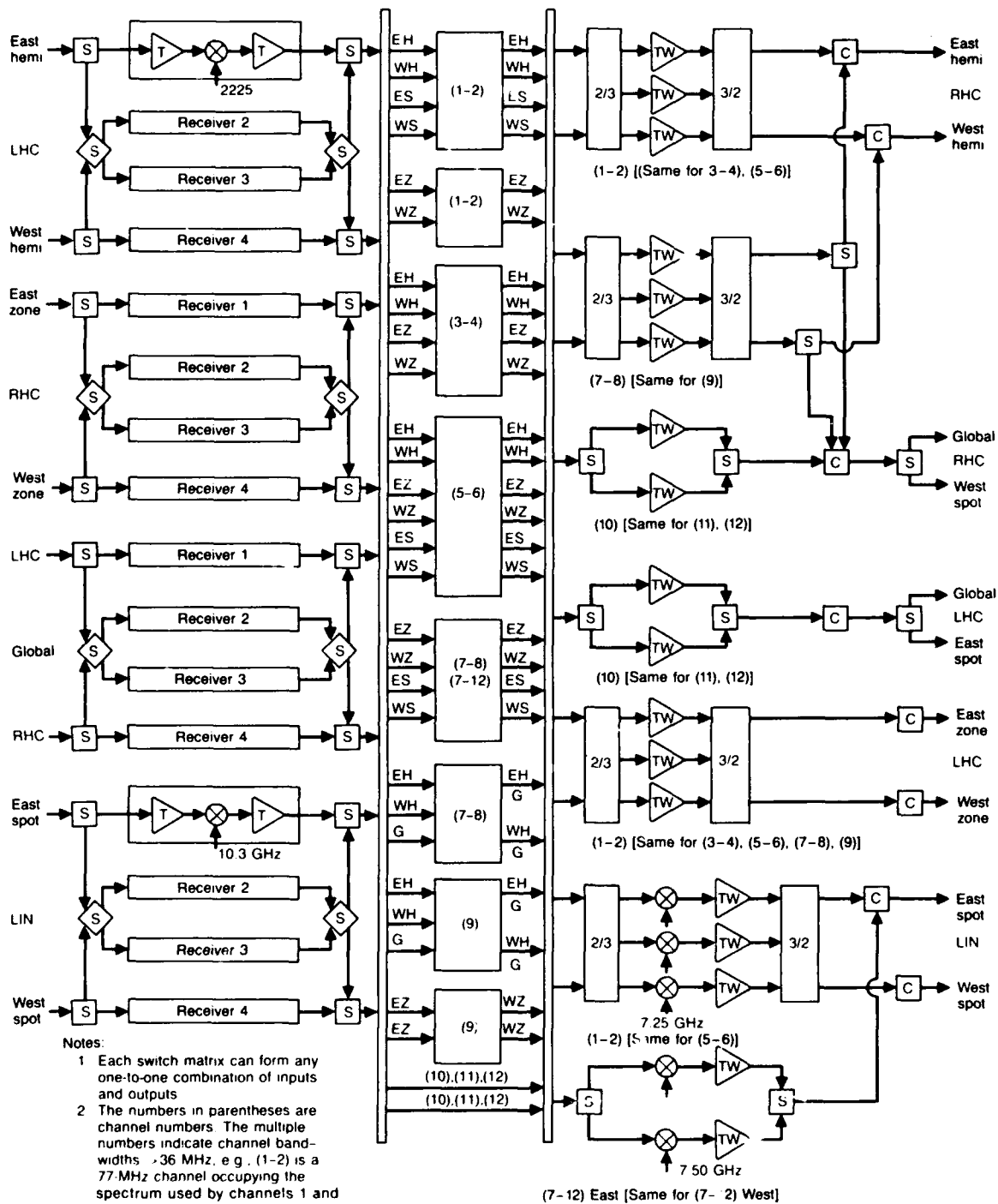
11/14 GHz: 10.954 to 11.191 GHz, and 11.459 to 11.698 GHz (plus option to switch from the lower band to 11.7 to 11.95 GHz or 12.5 to 12.75 GHz, on F-4 to F-6)

One 10-W TWT per repeater (one for one redundancy for 241-MHz repeaters, one for two redundancy for 72- to 77-MHz repeaters)

ERP (specified minimums): 41.1 dBW (east spot), 44.4 dBW (west spot)

Receiver

4/6 GHz: 5929 to 6423 MHz



Intelsat V-A communication subsystem.

Six active receivers with six spares, FET preamplifiers, 4.3 dB receiver noise figure

G/T: -16.0 dB/K (global beam), -9.0 dB/K (hemispheric beam), -6.0 dB/K (zone beam), all minimum values, FET preamplifier

14 GHz: 14.004 to 14.498 GHz

Two active receivers with two spares, FET preamplifiers, 6.8 dB receiver noise figure

G/T: +1 dB/K (east spot), +4.3 dB/K (west spot), both minimum values

Antenna

4/6 GHz: two earth coverage horns (one transmit, one receive); 18-deg/22-deg beamwidths, 16.5-dB/14.5-dB minimum gains; two reflectors (96-in. dia. transmit, 61-in. dia. receive), each with 88-horn feeds, each generating two hemispheric beams (21.5-dB minimum gain) and two smaller zone beams (24.5-dB minimum gain); zone beams each overlap a portion of one of the hemispheric beams and are separated by orthogonal polarizations; beam shapes are optimized to cover specified terminal locations; one feed horn is associated with each of the 11/14-GHz reflectors for transmission only, 5-deg beamwidth, 26.2-dB minimum gain; circular polarization; minimum interbeam spatial or polarization isolation 27 dB

11/14 GHz: two reflectors (one east, one west) each generating one beam for transmission and reception; west beam is 1.6 deg with minimum gain of 36 dB, east beam is 1.8 deg \times 3.2 deg with minimum gain of 33 dB; each beam steerable over a limited portion of the earth; linear polarization; minimum interbeam spatial isolation 27 dB

Design life

Ten years

Orbit

Synchronous equatorial, stationkeeping to $\pm 0.1^\circ$ N-S and E-W

Orbital history

Intelsat V-A satellites are often called Intelsat V F-10 to F-15

Satellite, launch date, service area, and comments:

F-1, 22 March 1985, Pacific, 174 E longitude

F-2, 30 June 1985, Indian, 63 E longitude

F-3, 29 September 1985, Atlantic, 1 W longitude, leased service

F-5, Launch vehicle failure May 1986

F-4, 17 May 1988, Atlantic, 53 W longitude, leased service

F-6, 26 January 1989, Indian, 60 E longitude

Atlas-Centaur launch vehicle (F-1 to F-3)

Ariane launch vehicle (F-4 to F-6)

Management

Developed by Ford Aerospace and Communications Corporation and subcontractors from France, West Germany, the United Kingdom, Italy, Japan, and Canada, for Intelsat

Operated by Intelsat

In the communications subsystem, three global beam transponders were added. They use the same frequency as the existing, dedicated global beam transponders but use the opposite polarization. Two Channel 9 zone beam transponders were also added. They are separated from each other by the spatial discrimination between the east and west zone beams. They are separated from the existing Channel 9 transponders by opposite polarizations. Another communications subsystem change is the addition of 4-GHz feed horns to the steerable east and west spot-beam antennas, which were previously used only at 11 and 14 GHz. The channels received on the global beams can be switched, in groups, between global transmit beams and these new 5-deg beams. These beams are intended for use with transponders leased by Intelsat for domestic communications systems. The last three satellites have the capability to switch channels (1-2) and (5-6) between the 10.95- to 11.2-GHz band, available on all Intelsat Vs and V-As, and the 11.7- to 11.95-GHz or 12.5- to 12.75-GHz bands. These latter bands will allow Intelsat more flexibility in the use of international frequency allocations and are specifically intended for a new Intelsat Business Service to smaller ground terminals. (Satellites with the business services modification are occasionally called Intelsat V-AB or V-B).

The first Intelsat V-A was launched in March 1985. Two others were launched later in 1985. A fourth was lost in a launch vehicle failure in 1986. The last two were launched in 1988 and 1989. All five satellites are in use.

* * * * *

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PAN AMERICAN SATELLITE

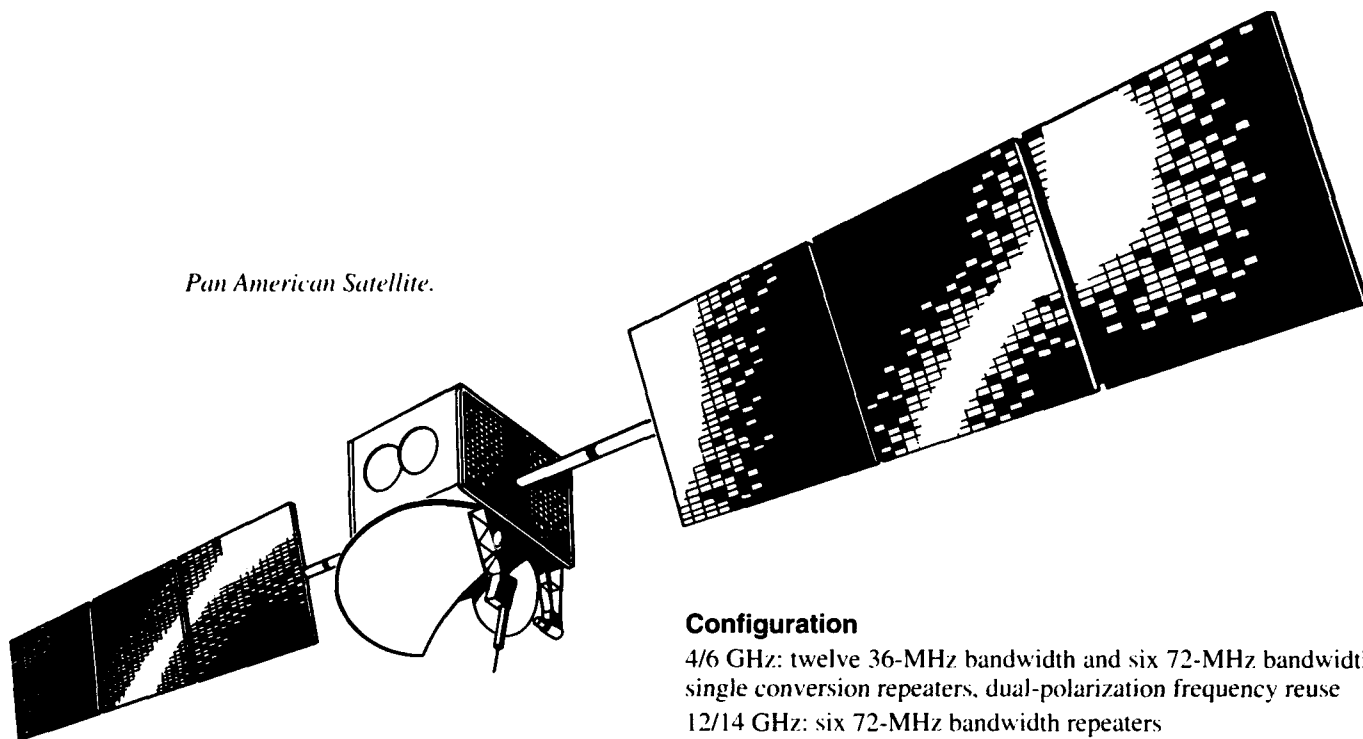
In 1984, Pan American Satellite [1-7] was one of several companies requesting Federal Communications Commission (FCC) permission to operate a private international satellite communications system.¹ In contrast to the other applications, which were for transmissions between the United States and western Europe, Pan American Satellite's application was for services within Latin

America and between the United States and Latin America. They received preliminary FCC approval in 1985.

Pan American Satellite's first customer was in Peru. This service was coordinated technically and economically with Intelsat in 1987. Later that year, the company received its final FCC authorization and launched its satellite in 1988. However, the satellite that was launched was not limited to the Latin American service originally envisioned. It also has the capability to provide services between the United States and Europe.

¹ Some of the public policy debates concerning this subject are described in the later section on the Orion system.

Pan American Satellite.



This change was the result of two business deals. The first was the purchase, in 1985, of a partially built but unwanted satellite ordered by American Satellite Corporation (ASC). This satellite, which was completed for Pan American Satellite, had 12/14-GHz transponders in addition to 4/6-GHz transponders. The latter already had been planned for Latin American service; the former were well suited to transatlantic service. The primary change in the satellite was an antenna redesign to provide the beam shapes and locations required by Pan American Satellite. This technical capability to serve Europe was complimented by the second business deal: the purchase, in 1987, of Cygnus Satellite Corporation which had preliminary FCC approval for transatlantic services.

Except for its antenna beam patterns, the satellite is similar to many built for United States domestic communication systems. It has a box-shaped body with solar panels that deploy in orbit. The antennas are fixed on the earth-viewing face of the satellite. The 4/6-GHz part of the communication subsystem is used for Latin American service. The transponders can be switched between a broad Latin beam, which covers Central and South America and the Caribbean, and three spot beams, which together cover the same parts of the globe. The 12/14-GHz part of the communication subsystem is for transatlantic service. For transmission, three transponders are connected to the European beam and three to the United States beam. Uplinks from either continent can be routed to any transponder. Additional satellite and payload details are as follows:

Satellite

Box body, about 5 ft on a side; height including antenna and feeds about 10 ft; 52-ft span across deployed solar panels

1560 lb in orbit, beginning of life

Sun-tracking solar arrays and NiH₂ batteries, approximately 1300 W after ten years

Three-axis stabilization, approximately ± 0.2 -deg accuracy

Solid rocket motor for apogee maneuver, liquid propulsion for on-orbit use

Configuration

4/6 GHz: twelve 36-MHz bandwidth and six 72-MHz bandwidth single conversion repeaters, dual-polarization frequency reuse

12/14 GHz: six 72-MHz bandwidth repeaters

Transmitter

4/6 GHz: 3700 to 4200 MHz

8.5-W transistor amplifiers for 36-MHz transponders in two sets of seven amplifiers for six transponders

16.2-W TWTAs for 72-MHz transponders in two sets of four amplifiers for three transponders

Beam center ERPs: 37.5/39.5 dBW for Latin beam, 40/42.5 dBW for spot North and Central beams (36/72-MHz transponders), 1.5 dB lower for South beam

12/14 GHz: 11.45 to 11.7 GHz (to Europe), 11.7 to 11.95 GHz (to United States)

Seven 16.2-W TWTAs for six transponders

Beam center ERPs: 45.5 dBW (United States), 47.5 dBW (Europe)

Receiver

4/6 GHz: 5925 to 6425 MHz

Two active receivers plus two spares

Peak G/T -0.5 dB/K

12/14 GHz: 14.0 to 14.5 GHz

One active receiver plus one spare

Peak G/T 0 dB/K

Antenna

4/6 GHz: Latin beam covers Central and South America and the Caribbean; North spot beam covers northwestern South America, Central America, and the Caribbean; Central spot beam covers central and west-central South America; South spot beam covers southern South America

12/14 GHz: United States beam covers the United States, except for the Pacific time zone, plus southeastern Canada; European beam covers west and east Europe except northern Scandinavia

Design life

Ten years nominal, thirteen years expected

Orbit

Synchronous equatorial, stationkeeping to $\pm 0.1^\circ$ N-S and E-W

Orbital history

1: launched 15 June 1988, 45°W longitude

Ariane launch vehicle

Management

Developed by RCA Astro Electronics (now GE Astro-Space) for Pan American Satellite

Satellite control and monitoring by Con-
tel ASC for Pan American Satellite

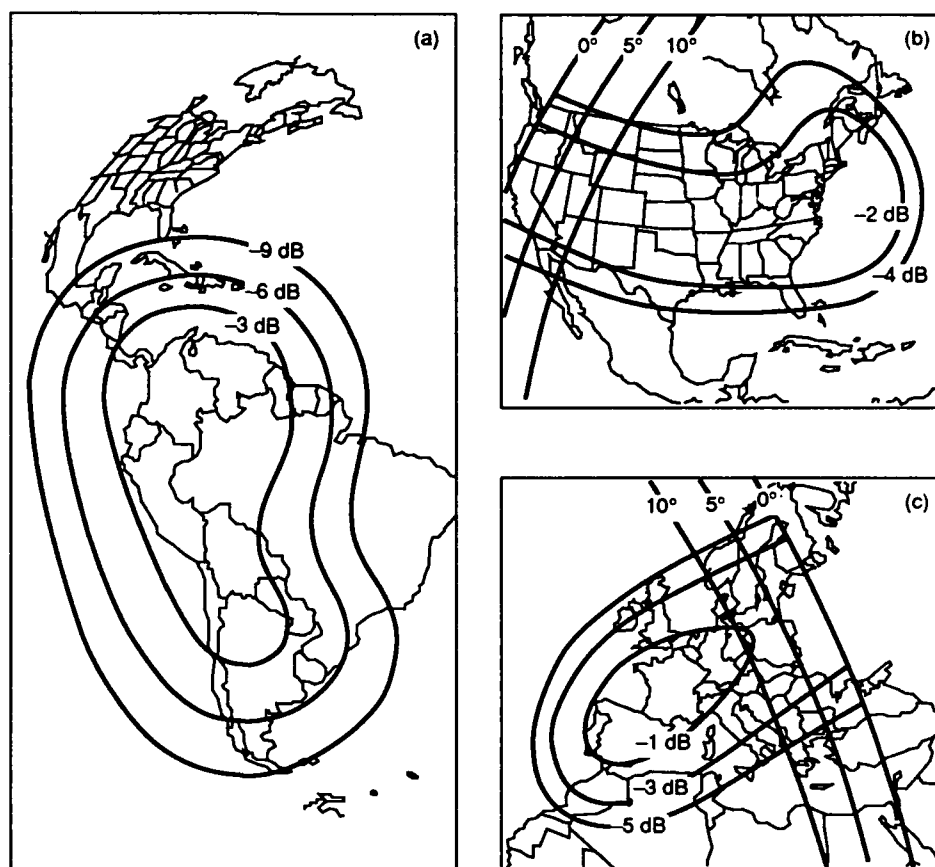
Since its satellite launch in 1988, Pan American Satellite, through its marketing and managing corporate alter ego, Alpha Lyracom Space Communications, has reached agreements with customers in many nations. In addition to these commercial agreements, the ground station operator in each country had to receive approval from its government, and the service had to pass through the Intelsat coordination process. The successes in these arenas between mid-1988 and the end of 1990 was a sharp contrast with the near total lack of success in prior years.

Pan American Satellite now provides both public and private domestic communications in many Central and South American countries. The communications are primarily television. It also has many customers for international television distribution and exchange of television programs between broadcasters in various countries. Other services are international business networks and international data distribution. Either full-time or occasional-use services have linked or will link almost all Latin and European nations. Links between Latin and European nations are not possible directly through the satellite, but they are realized by double-hop transmission through a Pan American Satellite ground station in Florida.

In August 1991, Pan American Satellite awarded a contract for the development of three new satellites, each with forty-eight transponders. The first launch is planned for 1994.

* * * * *

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Pan American Satellite antenna patterns. (a) Latin beam; (b) United States beam; (c) European beam.

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INTELSAT VI

The Intelsat V satellites were introduced into the Intelsat system in 1981. However, studies of higher capacity satellites using new or improved technologies had begun several years earlier. The major technologies considered were increased frequency reuse, use of newly allocated portions of spectrum adjacent to existing 4/6-GHz and 11/14-GHz bands, active switching on-board the satellite, increased ERP in some channels, and intersatellite links.

The actual Intelsat VI design [1-15] incorporates all except the last.

The satellite is a new design but incorporates features from the Leasat and HS-376 designs. (The latter is used for SBS, Anik C, and many other domestic communications satellites.) The basic satellite body is about 11 ft in diameter and about 6-1/2 ft high. The upper portion of the cylindrical surface of this section is a

thermal radiator; the lower portion is part of the solar array. The remainder of the solar array is a drum about 12-1/2 ft high, which fits around the main body during launch and is deployed in orbit to the configuration shown in the satellite figure. Small adjustments to the deployed position can be made to maintain the in-orbit balance of the satellite. The main body includes a liquid propellant system, which is used for both the apogee boost maneuver and for on-orbit stationkeeping and attitude control adjustments. Satellite and communication subsystem details are as follows:

Satellite

Cylinder, 142-in. (11.8-ft) dia., stowed height 210 in. (17.5 ft), main section approximately 86-in. height, deployed section approximately 149-in. height [464 in. (38.7 ft) overall]

Approximately 4600 lb in orbit, beginning of life, 4130 lb at end of life

Solar cells and NiH_2 batteries, more than 2600 W beginning of life, approximately 2200 W at end of life

Spin-stabilized, gyrostator, approximately 30 rpm, antenna pointing accuracy ± 0.05 deg

Bipropellant liquid propulsion for apogee maneuver and on-orbit use

Configuration

4/6 GHz: Thirty-eight single-conversion repeaters with bandwidths of 36 to 72 MHz, sixfold frequency reuse except in global beams

11/14 GHz: Ten double-conversion repeaters with bandwidths of 72 to 159 MHz; dual-beam frequency reuse

Capacity

Nominal capacity approximately 24,000 two-way voice circuits (capacity approximately 120,000 circuits with full use of digital circuit multiplication techniques) plus three TV transmissions

Transmitter

4/6 GHz: 3629 to 4198 MHz

Global beam: one 16-W TWT per repeater

Hemispheric beam: eight repeaters have 20-W TWTs, two have 40-W TWTs

Zone beam: one 5.5-W TWT per SE and SW repeater, one 2-W FET amplifier per NE and NW repeater

All amplifiers have one spare per two repeaters

Minimum ERP: 26 dBW (global beam), 34-37 dBW (hemispheric beams), 31 dBW (zone beams); channel (9) 1 to 2 dB lower

11/14 GHz: 10.954 to 11.191 GHz, and 11.459 to 11.698 GHz

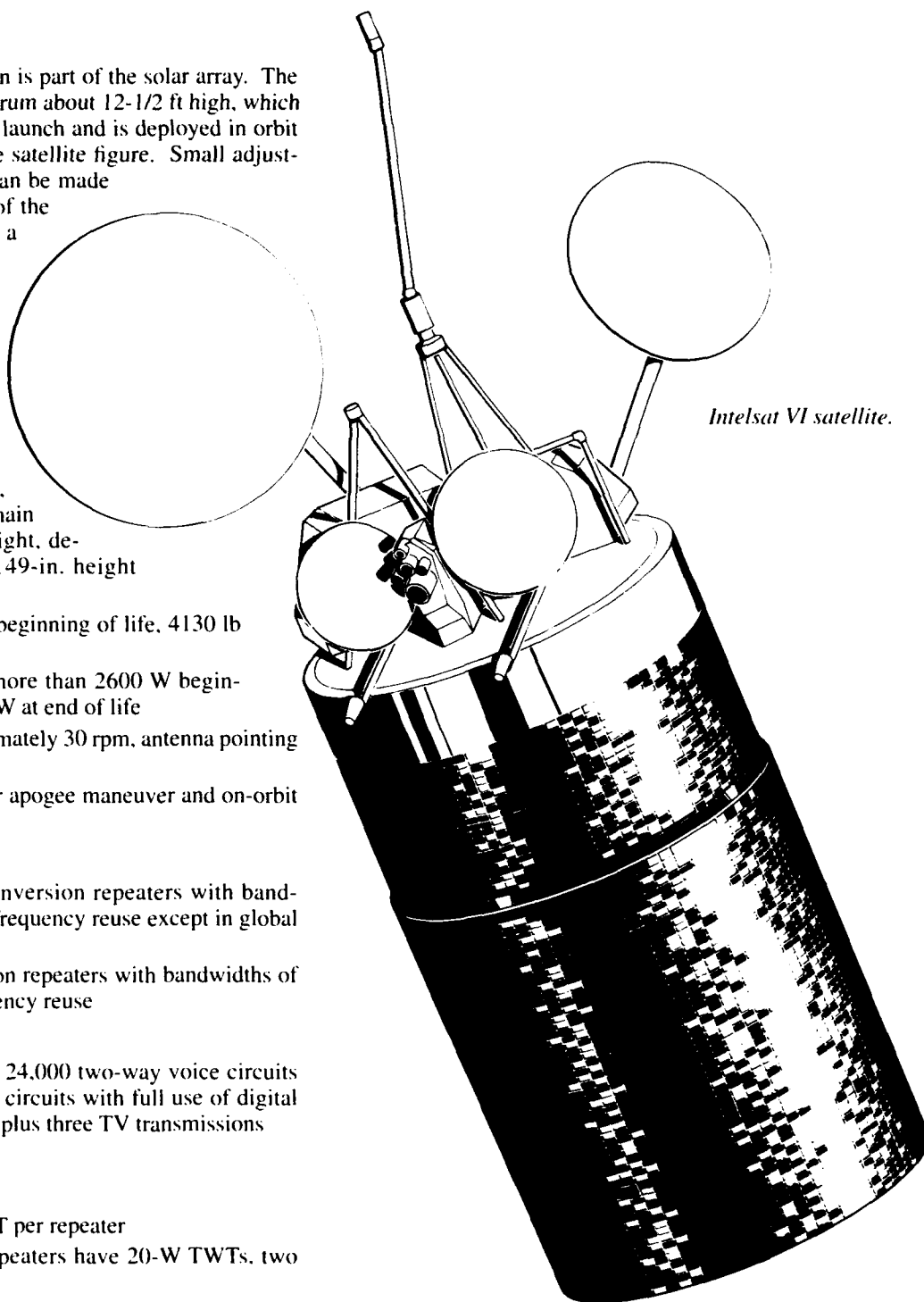
One 8.5-W TWT plus one spare per repeater

ERP (minimum): 41 dBW (east spot), 44 dBW (west spot)

Receiver

4/6 GHz: 5854 to 6423 MHz

Eight active receivers plus eight spares, FET preamplifiers, 3.2-dB receiver noise figure



Intelsat VI satellite.

G/T (minimum): -16 dB/K (global beam), -9 dB/K (hemispheric beam), -6 dB/K (zone beam); typical performance up to several dB better

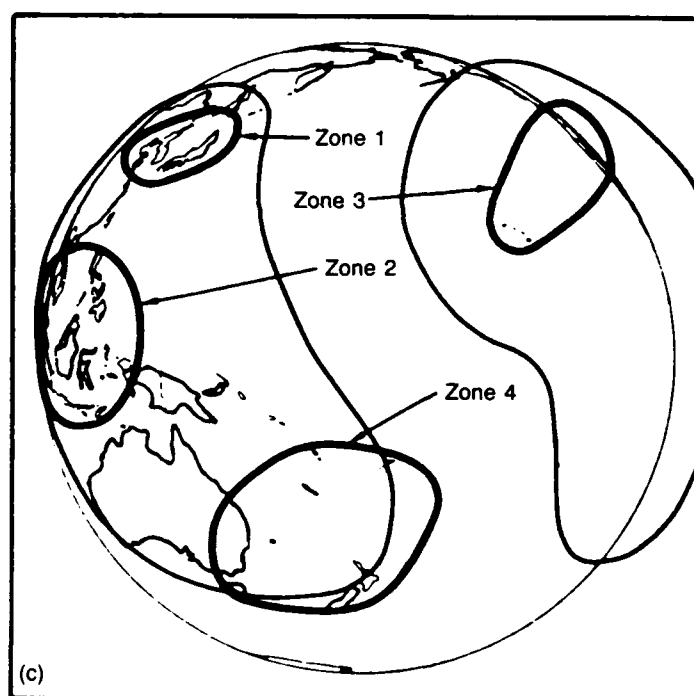
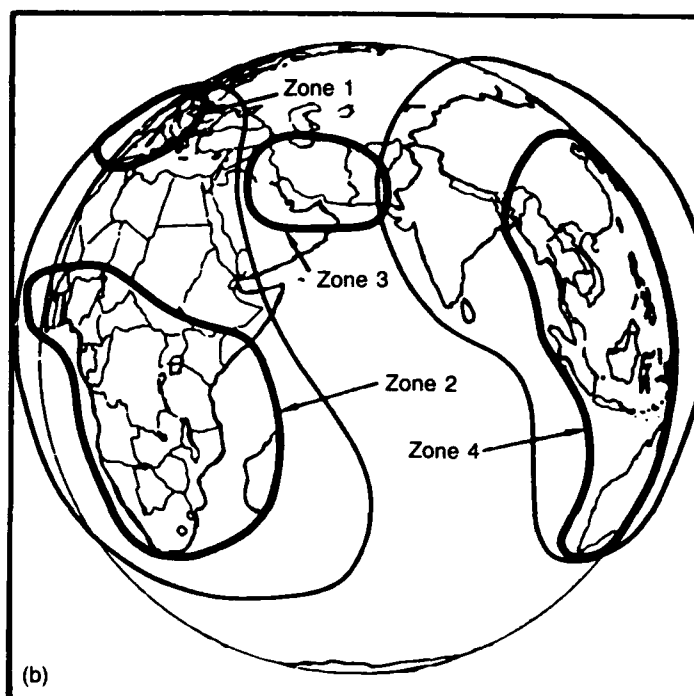
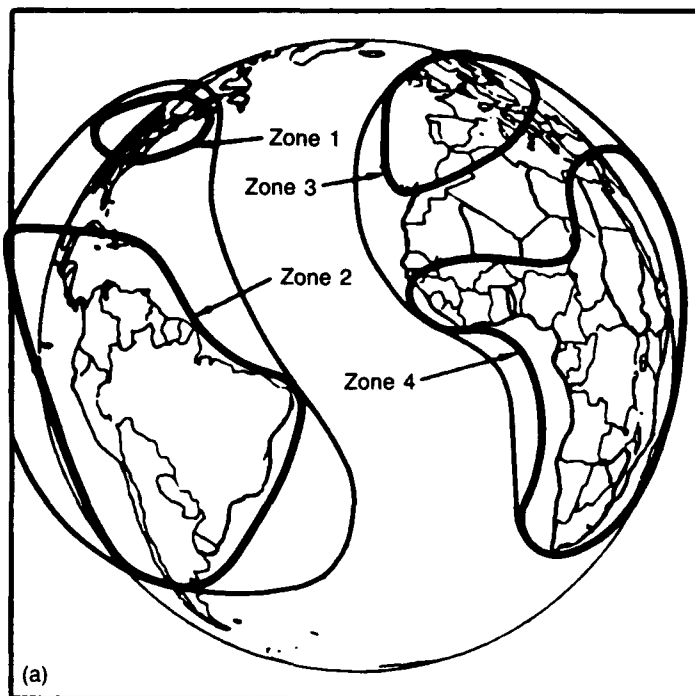
11/14 GHz: 14.004 to 14.498 GHz

Two active receivers plus two spares, FET preamplifiers, 5.0-dB receiver noise figure

G/T (minimum): +1 dB/K (east spot), +4 dB/K (west spot); typical performance a few dB better

Antenna

4/6 GHz: two earth coverage horns; two reflectors (126-in. dia. transmit, 79-in. dia. receive), each with 147 feed horns, each generating two hemispheric beams and four smaller reconfigurable



Intelsat VI antenna patterns. (a) Atlantic Ocean; (b) Indian Ocean; (c) Pacific Ocean.

zone beams; zone beams overlap parts of the hemispheric beams and are separated by orthogonal polarizations; beam shapes are optimized to cover specified terminal locations; each array of feed horns has four distribution networks: one for hemispheric beams and three (switchable between Atlantic, Indian, and Pacific coverage patterns) for the zone beams; circular polarization; minimum interbeam spatial or polarization isolation 27 dB

11/14 GHz: two reflectors (one west, one east) each generating one beam for transmission and reception; 43- and 39-in. dia.; west beam is 1.6 deg with minimum gain of 36 dB, east beam is 1.8 x 3.2 deg with minimum gain of 33 dB; each beam is steerable over a limited portion of the earth; linear polarization; minimum interbeam spatial isolation 33 dB

Design life

Thirteen years

Orbit

Synchronous equatorial, stationkeeping to $\pm 0.1^\circ$ N-S and E-W

Orbital history

Satellite, launch date, service area, comments:

F-2, 27 October 1989, Atlantic, 24.5°W longitude

F-3, 14 March 1990, stabilized in low earth orbit after launch vehicle malfunction, transfer to operational orbit expected after addition of new propulsion by May 1992 Shuttle flight

F-4, 23 June 1990, Atlantic, 27.5°W longitude

F-5, launched 19 August 1991, in test

F-1, launched 29 October 1991, in test

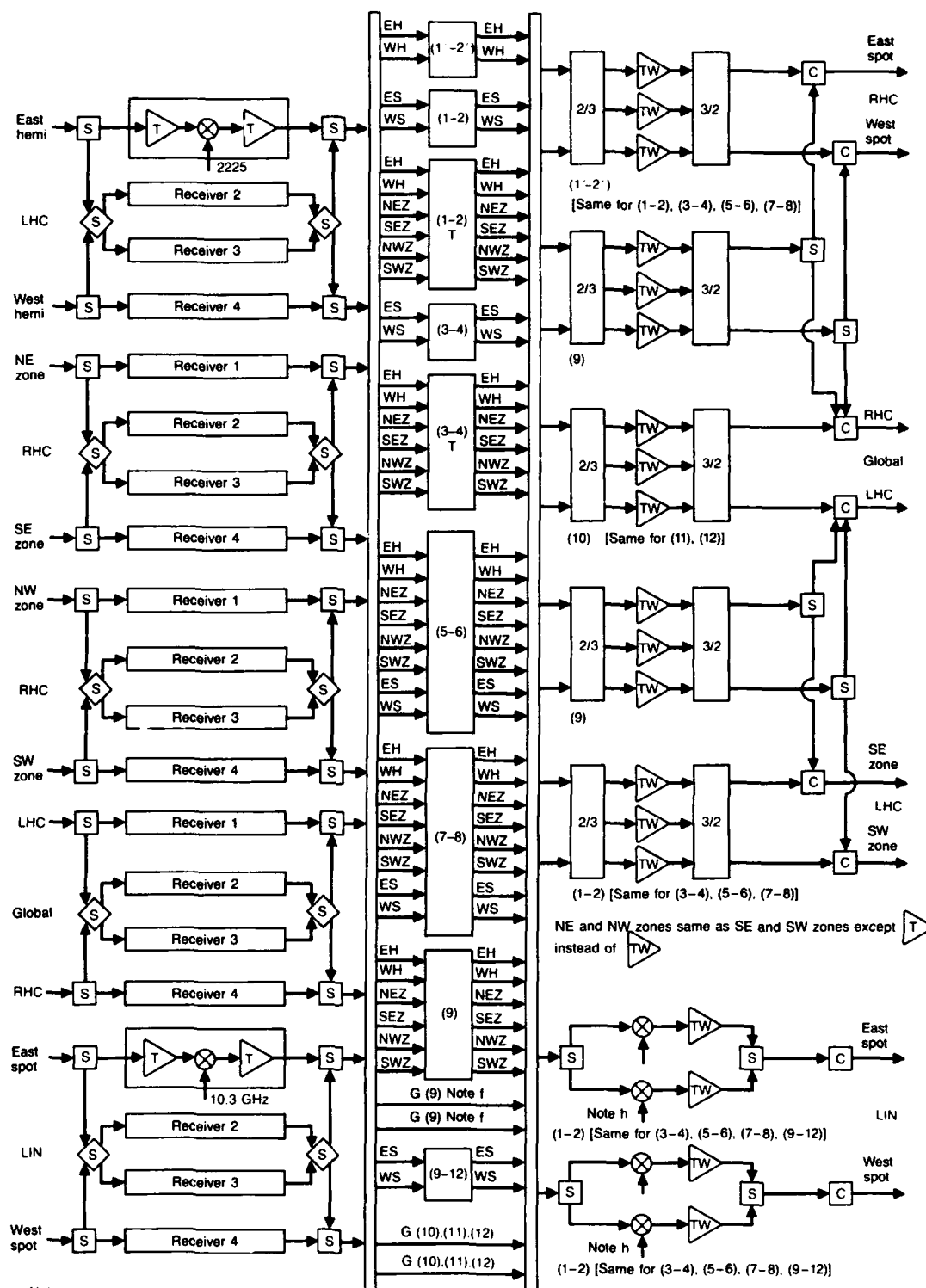
Ariane (F-1, F-2, F-4, F-5), Titan (F-3)

Management

Developed by Hughes Aircraft Company for Intelsat. Approximately 22% subcontracted to companies in the United Kingdom, France, Italy, Japan, West Germany, and Canada

Operated by Intelsat

The communications equipment is mounted on a despun shelf within the spinning main body. (The deployed array spins with the body.) The antenna feed arrays and reflectors are also mounted to the despun shelf. There are six communications antennas. The global coverage transmission and reception beams each have a dual-polarized horn. The largest deployed reflector produces six 4-GHz transmit beams. The second deployed reflector provides the corresponding 6-GHz receive beams. Two of the beams provide east and west hemispheric coverage. They share a common polarization and frequency plan, their signals kept separate



Notes

- The numbers in parentheses are channel numbers. The multiple numbers indicate channel bandwidths, > 36 MHz, e.g., (1-2) is a channel occupying the spectrum used by channels 1 and 2 on Intelsat IV.
- (1-2) occupies the spectrum just below (1-2).
- Each switch matrix can form any one-to-one combination of inputs and outputs.
- The switch matrices marked "T" can be used for SS/TDMA.
- LHC/RHC = Left/right-hand circular polarization. LIN = Linear polarization.
- Channel 9 may be used on both EH and WH or on the co-polarized global beam. It may also be used in all 4 zones or on the co-polarized global beam.
- Spot-beam antennas have 11/14 GHz diplexers (not shown).
- 7.25 GHz for (1-2), (3-4), (5-6). 7.50 GHz for (7-8), (9-12).
- Combiners after transmitters also have inputs from unillustrated transmitters.

Intelsat VI communication subsystem.

by the directions of the two beams. The other four are zone beams. They use the same frequencies as the hemispheric beams but the opposite polarization. The four are separated from each other by their directions, which are nominally northeast, northwest, southeast, and southwest. The southern zone beams are larger than the northern zone beams, because they serve population centers in the equatorial and southern parts of the globe, which are more dispersed than those in the northern part of the globe. The hemispheric beam patterns are fixed, but the zone beams have three patterns, one for each ocean region, which can be switched in orbit. Examples of the hemispheric and zone beams are shown. The two smaller reflectors provide steerable east and west spot beams for 11-GHz transmission and 14-GHz reception. The large hatbox-shaped objects behind these two reflectors contain the more than one hundred feed horns for the 4- and 6-GHz reflectors. These complex feed arrays allow the beams to be shaped to a reasonable match to the geographic areas they serve. The feed arrays can be switched to different configurations depending on the ocean region where the satellite is located.

The switch matrices in the center column of the communication subsystem diagram allow many different interconnections between the various beams. This flexibility allows the satellite to be in a configuration that is best suited to the traffic pattern that it is handling. Most of the switch matrices are changed infrequently by ground command. Two may be switched, according to a ground-controllable pattern stored on the satellite, through several states within a 2-msec frame. This capability will be used in a satellite-switched TDMA (SS/TDMA) mode which will significantly increase the satellite's capacity relative to frequency division multiple access (FDMA) operation.

Development of the satellites started in March 1982. Critical new technology feasibility had been proved earlier through several studies sponsored by Intelsat and others. The present contract covers five satellites with options for more. The first satellite was launched in October 1989 and began full operational service in spring 1990, although it had been used as early as December 1989. The second satellite could not be separated from the launch vehicle and was put into a stable low orbit by use of on-board propulsion, after separation from its perigee motor. A shuttle repair mission is being planned for 1992 to install a new perigee motor on the satellite. The third satellite was launched successfully and is operating with the first. One more launch is scheduled; it is unlikely that options for additional satellites will be exercised.

* * * * *

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ASIASAT

Asia Satellite Telecommunications Company, based in Hong Kong, offers domestic and international communications in Asia through its Asiasat satellite [1-2]. The company is an equal partnership of a prominent Hong Kong trading conglomerate, an organization set up by the Peoples Republic of China, and a large British telecommunications company.

The Asiasat is the refurbished Westar VI. It was launched in 1984 but was stranded in low orbit by a rocket motor failure. The satellite was retrieved by the Shuttle later that same year and returned to earth. Lloyds of London made an insurance payment to the original owners to cover their loss and took possession of the satellite. The satellite was purchased from them by Asia Satellite

Telecommunications and refurbished by its manufacturer. The key items of the refurbishments were replacement of the batteries, the failed motor, and some small thrusters; and antenna feed modification to provide a beam pattern suitable for Asia. Details of the satellite are:

Satellite

Cylinder, 85-in. dia., 269-in. height (22.4 ft) when deployed
1340 lb in orbit, beginning of life

Solar cells and NiCd batteries, 840 W at beginning of life, 700 W at end of life

Spin-stabilized, gyrostad, 55 to 60 rpm

Solid rocket motor for apogee maneuver, liquid propulsion for on-orbit use

Configuration

Twenty-four 36-MHz bandwidth single-conversion transponders, dual-polarization frequency reuse

Transmitter

3702 to 4198 MHz

Six sets of five 8-W TWTAs for four transponders

Peak ERP approximately 37 dBW per transponder

Receiver

5927 to 6423 MHz

Two active plus two spare receivers

Antenna

Two 72-in. dia. paraboloids with polarizing grids, one behind the other; one north beam covering China, Mongolia, Korea, Japan, and Taiwan; one south beam covering Turkey through India to the Philippines; beams on orthogonal linear polarizations

Design life

Ten years

Orbit

Synchronous equatorial, stationkeeping to $\pm 0.1^\circ$ N-S and E-W

Orbital history

Launched 7 April 1990, in use

Long March III launch vehicle

Management

Developed by Hughes Aircraft Company

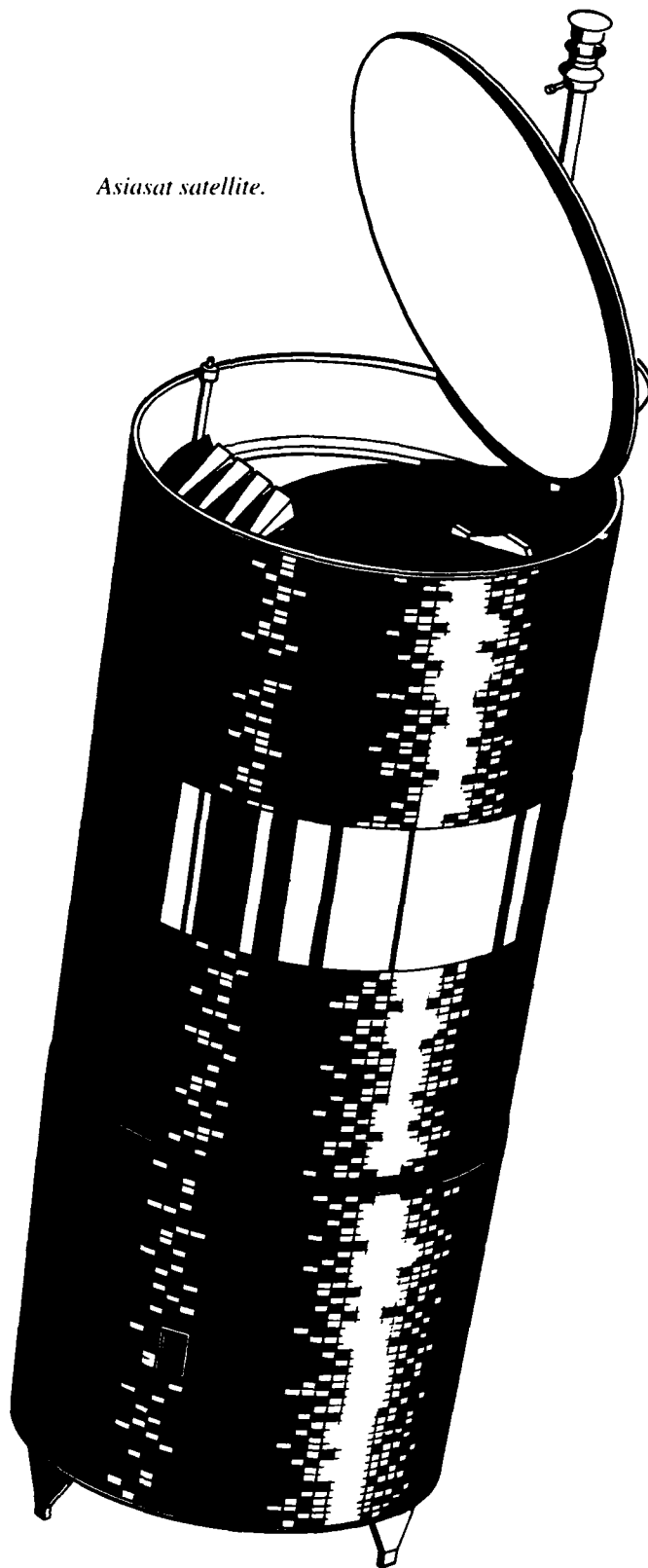
Operated by Cable and Wireless for Asia Satellite Telecommunications

The satellite was launched from China, which required approval from the United States Government, which was concerned about satellite technology transfer to China. A condition of the approval was that the satellite remain under constant supervision by United States nationals while in China. Prior to launch, there was interest in the satellite within many nations, but few commitments. However, after launch, many transponder leases were quickly signed.

The satellite is now being used for domestic and international communications by Thailand, South Korea, Burma, Mongolia, China, and Hong Kong. Other customers could include Pakistan, Nepal, and Bangladesh. Uses vary from basic telephone service to television distribution to international business data networks.

Because most of the Asiasat capacity is leased, the company is planning for a second satellite to be launched in 1993 or 1994. In

Asiasat satellite.



addition, it is working with Thailand to develop a concept for a national satellite system, which would evolve from Thailand's use of Asiasat.

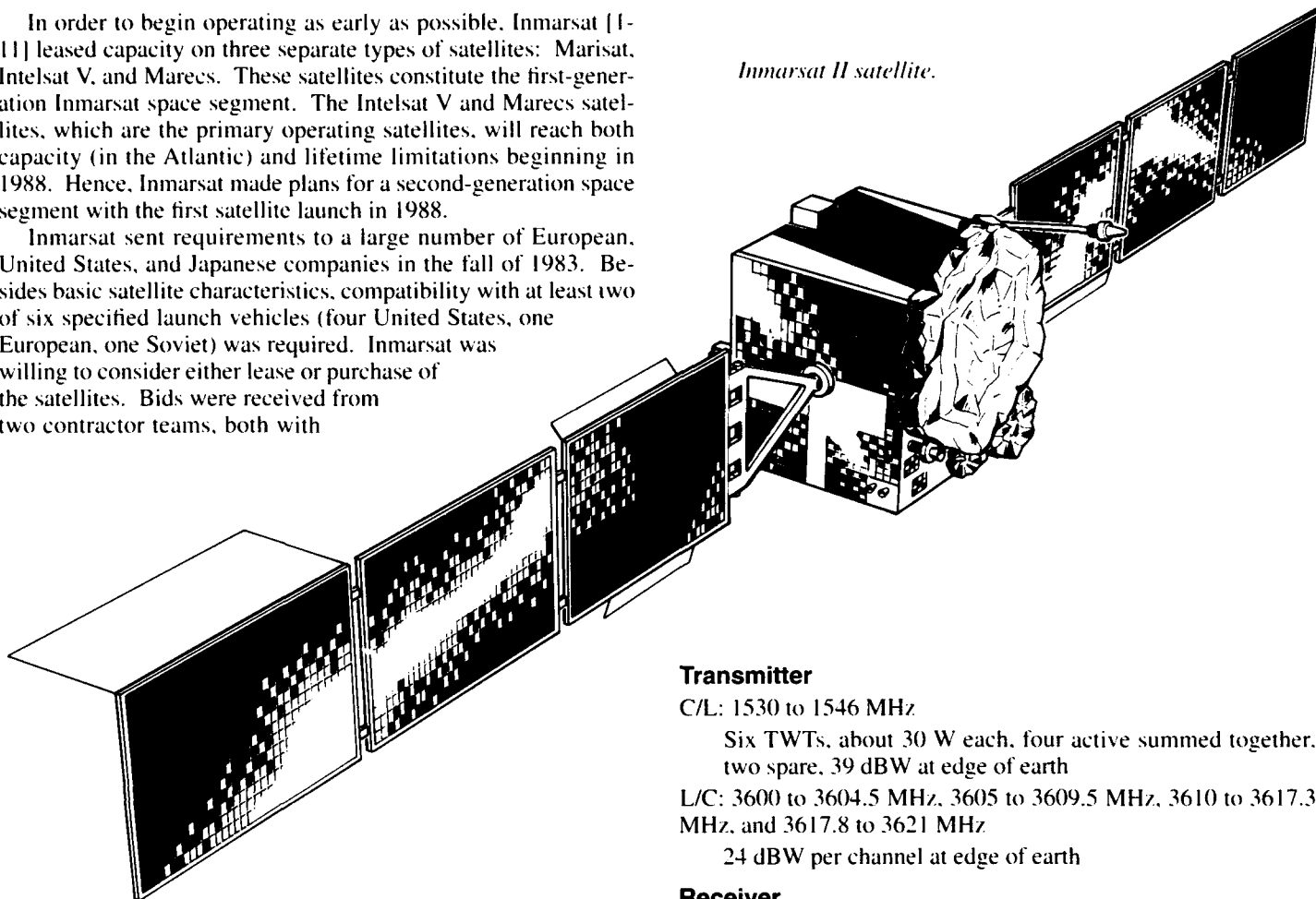
1. *Aviation Week & Space Technology* (5 December 1988), p. 34; (7 August 1989), p. 16; (16 April 1990), p. 25; (23 April 1990), p. 25; (15 October 1990), p. 13; (25 March 1991), p. 13.
2. B. Long, "Westar VI Resurfacing in Asia," *Satellite Communications* (October 1988).

INMARSAT II

In order to begin operating as early as possible, Inmarsat [1-11] leased capacity on three separate types of satellites: Marisat, Intelsat V, and Marecs. These satellites constitute the first-generation Inmarsat space segment. The Intelsat V and Marecs satellites, which are the primary operating satellites, will reach both capacity (in the Atlantic) and lifetime limitations beginning in 1988. Hence, Inmarsat made plans for a second-generation space segment with the first satellite launch in 1988.

Inmarsat sent requirements to a large number of European, United States, and Japanese companies in the fall of 1983. Besides basic satellite characteristics, compatibility with at least two of six specified launch vehicles (four United States, one European, one Soviet) was required. Inmarsat was willing to consider either lease or purchase of the satellites. Bids were received from two contractor teams, both with

Inmarsat II satellite.



British prime contractors, in April 1984, and a contract was signed with one a year later.

The Inmarsat II satellites are derived from the same basic design used for the European Communication Satellite (ECS) and Marecs. The rectangular body houses all the satellite equipment, except for the solar arrays and the antennas. The solar arrays are deployed in orbit, but the large L-band transmit array, visible in the figure as a hexagonal plate, is fixed to the satellite body. The satellite and payload details are as follows:

Satellite

Rectangular body, with antenna $8.4 \times 5.2 \times 4.9$ ft, 50 ft across tips of deployed solar array

Approximately 1500 lb in orbit, beginning of life

Sun-tracking solar arrays and NiCd batteries, approximately 1000 W after ten years

Three-axis stabilization

Configuration

One C/L-band channel for shore to ship; 16-MHz bandwidth

Four L/C-band channels for ship to shore; 4.5-, 4.5-, 7.3-, and 3.2-MHz bandwidths

Capacity

250 two-way voice circuits

Transmitter

C/L: 1530 to 1546 MHz

Six TWTs, about 30 W each, four active summed together, two spare, 39 dBW at edge of earth

L/C: 3600 to 3604.5 MHz, 3605 to 3609.5 MHz, 3610 to 3617.3 MHz, and 3617.8 to 3621 MHz

24 dBW per channel at edge of earth

Receiver

C/L: 6425 to 6441 MHz

-14 dB/K G/T

L/C: 1626.5 to 1631 MHz, 1631.5 to 1636 MHz, 1636.5 to 1643.8 MHz, and 1644.3 to 1647.5 MHz

-12.5 dB/K G/T

Antenna

L: 61-element array, beam shaped to give increasing gain from center to edge of earth (transmit); nine-element array (receive)

C: two seven-element arrays (one transmit, one receive)

All antenna elements are cup-backed crossed dipoles

All antennas are earth coverage, circular polarization

Design life

Ten years

Orbit

Synchronous equatorial

Orbital history

1: launched 30 October 1990, in use, 56° W longitude

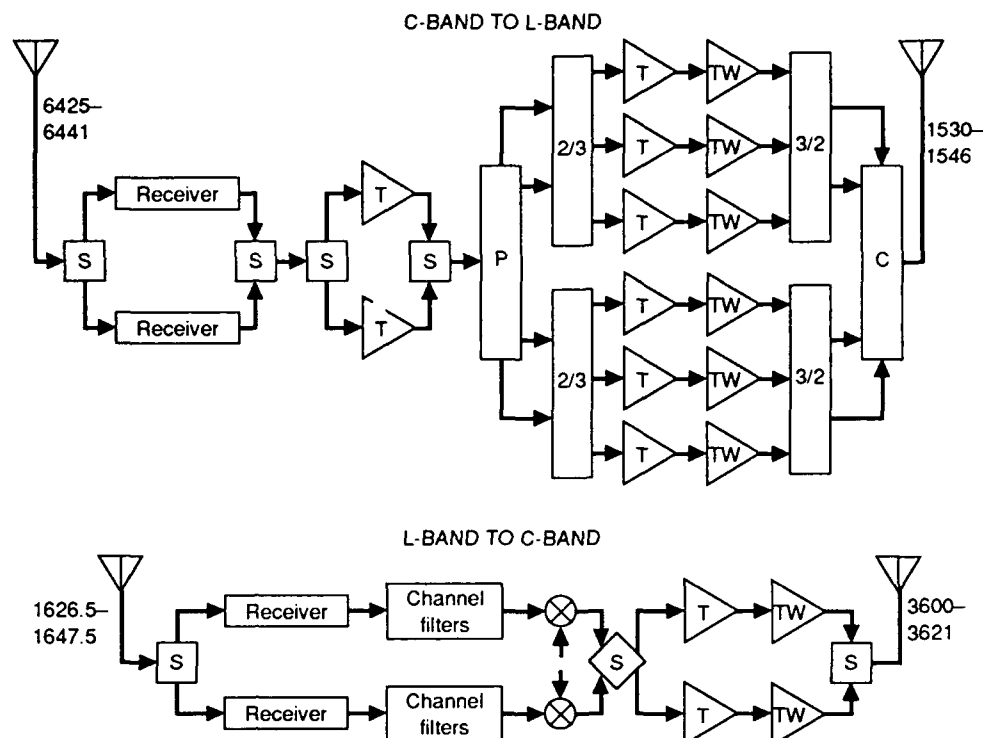
2: launched 8 March 1991, in use, 15.5° W longitude

3: launch scheduled December 1991 or early 1992

4: launch scheduled first half 1992

Delta 2 launch vehicle (1, 2)

Ariane launch vehicle (3, 4)



Notes

- Receivers include downconverters
- Channel filters' center frequencies near 60 MHz
- Driver amplifiers include predistortion circuits

Inmarsat II communication subsystem.

Management

Developed for Inmarsat by British Aerospace (prime) with Hughes Aircraft Company (payload) and other subcontractors in France, Japan, West Germany, and Canada

Operated by Inmarsat

The support subsystems are similar or identical in design to flight-proven hardware, but the payload is a new design. Relative to the first-generation satellites, the payload provides a significant capacity increase and operation on frequencies allocated for distress and for aircraft communications. The payload has one channel for shore-to-ship transmission and four channels for ship-to-shore transmission. The four channels allow a better matching of each channel to the characteristics of different classes of ship stations, all of which are moderately to severely limited in radiated power. The first ship-to-shore channel is for high-speed data, the second for low-power ship stations, the third for standard A ship stations, and the fourth for very-low-power stations, including standard C, emergency beacons, and aircraft. Standard stations are described later in the Inmarsat System discussion.

The satellite uses L-band (1.5 to 1.6 GHz) for communication with ships and C-band (4/6 GHz) for communication with shore stations. The L-band transmit antenna is a hexagonal array of 61 elements. The array is designed so that the gain is lower toward the subsatellite point and increases toward the edge of earth. This gain taper compensates for losses, which increase as the ship terminal elevation to the satellite decreases. The L-band transmitter uses any four of six available TWTs. Linearizers precede each TWT to increase channel capacity by reducing distortions; the outputs of the four active TWTs are coherently summed. The oth-

er transmit and receive antennas use smaller arrays of similar cup-dipole elements.

The Inmarsat II contract includes three satellites and options for six more. One of these options was converted to a firm order in 1988. The first two satellites were launched in October 1990 and March 1991. Both are in service over the Atlantic Ocean. The other two will be launched at the end of 1991 and the beginning of 1992. One will be positioned over the Indian Ocean and one over the Pacific Ocean.

* * * * *

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- A. F. Ghais, "Future Development of the Inmarsat System," Paper 84-0750, *AIAA 10th Communication Satellite Systems Conference* (March 1984).
- O. Lundberg, "The Inmarsat System and Its Future," *Space Communication and Broadcasting*, Vol. 2, No. 3 (September 1984).
- T. Pirard, "On Land, In the Air, On the Seas," *Satellite Communications*, Vol. 9, No. 11 (October 1985).
- Aviation Week & Space Technology* (8 August 1983), p. 20; (30 July 1984), p. 18; (11 March 1985), p. 27; (22 April 1985), p. 30; (29 July 1985), p. 24; (7 October 1985), p. 55; (28 July 1986), p. 25.
- Spaceflight*, Vol. 27, No. 7/8 (July/August 1985), p. 295.
- Flight International* (13 August 1983), p. 422; (10 August 1985), p. 34.
- P. Berlin, "Inmarsat's Second Generation Satellites," *IEE Proceedings*, Vol. 133, Part F, No. 4 (July 1986).

11. C. C. Huang and C. A. McDonach, "Antenna Design for the Inmarsat Second Generation Communication Satellites," *Microwave Journal*, Vol. 33, No. 2 (February 1990).

Antenna

One 58- x 65-in. reflector with multiple offset feed horns to form east and west beams in the northern hemisphere, linear polarization

Design life

Ten years

Orbit

Synchronous equatorial, stationkeeping to $\pm 0.1^\circ$ N-S and E-W

Orbital history

TDRS 3: launched 29 September 1988, 41° W longitude

TDRS 4: launched 13 March 1989, 171° W longitude
Shuttle/IUS launch vehicle

Management

Developed by TRW for NASA

Operated by Contel Federal Systems for NASA

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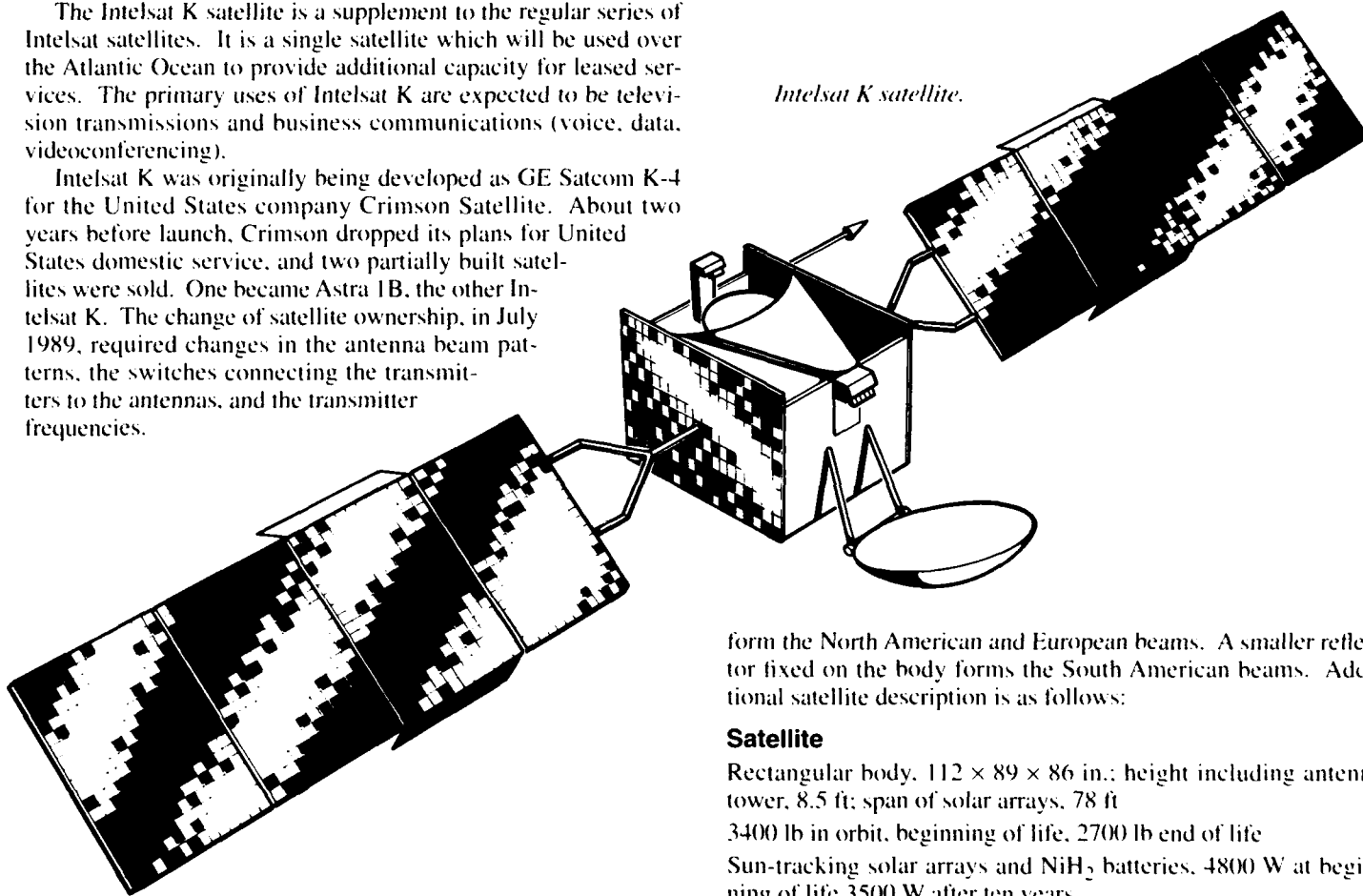
1. *Satellite Communications* (July 1990), p. 11; (August 1990), p. 11.

INTELSAT K

The Intelsat K satellite is a supplement to the regular series of Intelsat satellites. It is a single satellite which will be used over the Atlantic Ocean to provide additional capacity for leased services. The primary uses of Intelsat K are expected to be television transmissions and business communications (voice, data, videoconferencing).

Intelsat K was originally being developed as GE Satcom K-4 for the United States company Crimson Satellite. About two years before launch, Crimson dropped its plans for United States domestic service, and two partially built satellites were sold. One became Astra 1B, the other Intelsat K. The change of satellite ownership, in July 1989, required changes in the antenna beam patterns, the switches connecting the transmitters to the antennas, and the transmitter frequencies.

Intelsat K satellite.



Intelsat K has sixteen transponders. Eight are permanently connected to the European beam. Four may be individually connected to either the North American beam or the two South American beams, or both North and South beams. The other four transponders have the same flexibility for North and South America but may also be individually switched to the European beam. The South American beams are used only for transmitting; the North American and European beams are for both receiving and transmitting.

Intelsat K has a rectangular body with deployed solar arrays. A large reflector deployed from one side of the body is used to

form the North American and European beams. A smaller reflector fixed on the body forms the South American beams. Additional satellite description is as follows:

Satellite

Rectangular body, $112 \times 89 \times 86$ in.; height including antenna tower, 8.5 ft; span of solar arrays, 78 ft

3400 lb in orbit, beginning of life, 2700 lb end of life

Sun-tracking solar arrays and NiH_2 batteries, 4800 W at beginning of life, 3500 W after ten years

Three-axis-stabilized using a pivoted momentum wheel and magnetorquers, 0.1-deg accuracy in roll and pitch, 0.35 deg in yaw

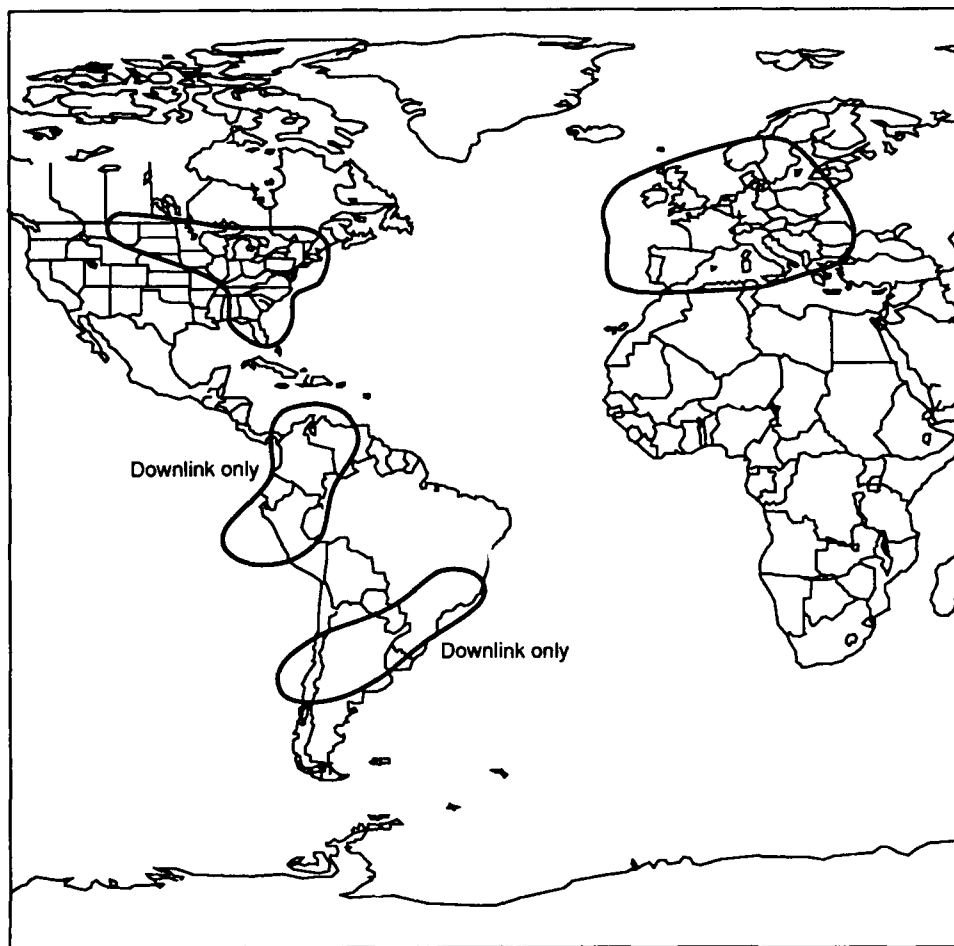
Bipropellant propulsion for apogee maneuver, monopropellant hydrazine for on-orbit use

Configuration

Sixteen 54-MHz bandwidth transponders, single conversion, dual-polarization frequency reuse

Capacity

Maximum of 65,000 voice circuits using digital circuit multiplication or 32 TV transmissions



Intelsat K antenna pattern.

Transmitter

11.45 to 11.95 GHz (to North and South America), 11.45 to 11.7 GHz and 12.5 to 12.75 GHz (to Europe)

62.5-W TWTAs per transponder, three spares for each group of eight transponders

ERP 50 dBW near centers of coverages; 47 dBW (North America), 45 dBW (South America), 42.7 dBW (North and South America), 47 dBW (Europe) at edge of coverage

Orbital history

Launch scheduled February 1992

Atlas II launch vehicle

Management

Developed for Intelsat by GE Astro Space

Operated by Intelsat

Receiver

14.0 to 14.5 GHz

Two active, two spare receivers

Antenna

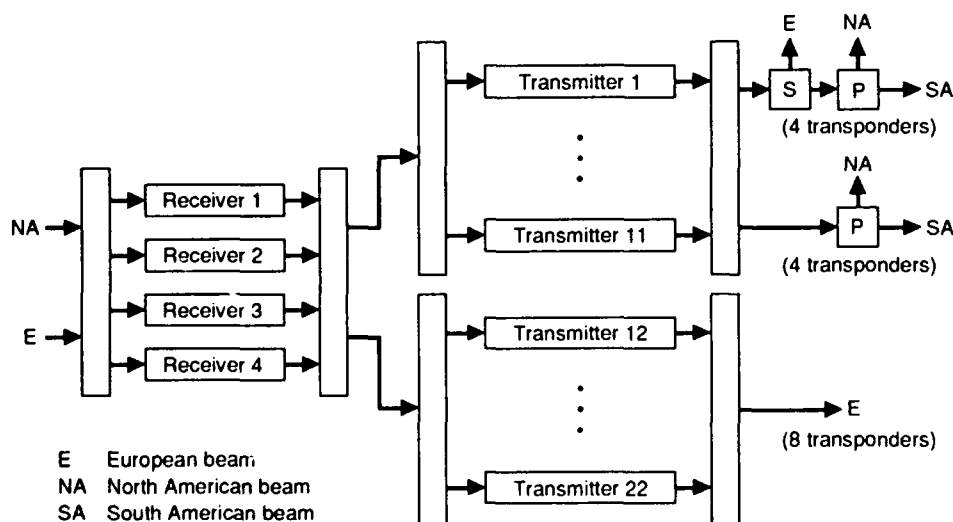
One 7-ft dia. offset fed parabolic reflector with multiple feed horns to form beams for North America and Europe; one 32- x 36-in. offset-fed parabolic reflector with multiple feed horns to form two beams for South America; orthogonal linear polarizations

Design life

Ten years

Orbit

Synchronous equatorial, 21.5°W longitude, stationkeeping to $\pm 0.05^\circ$ N-S and E-W

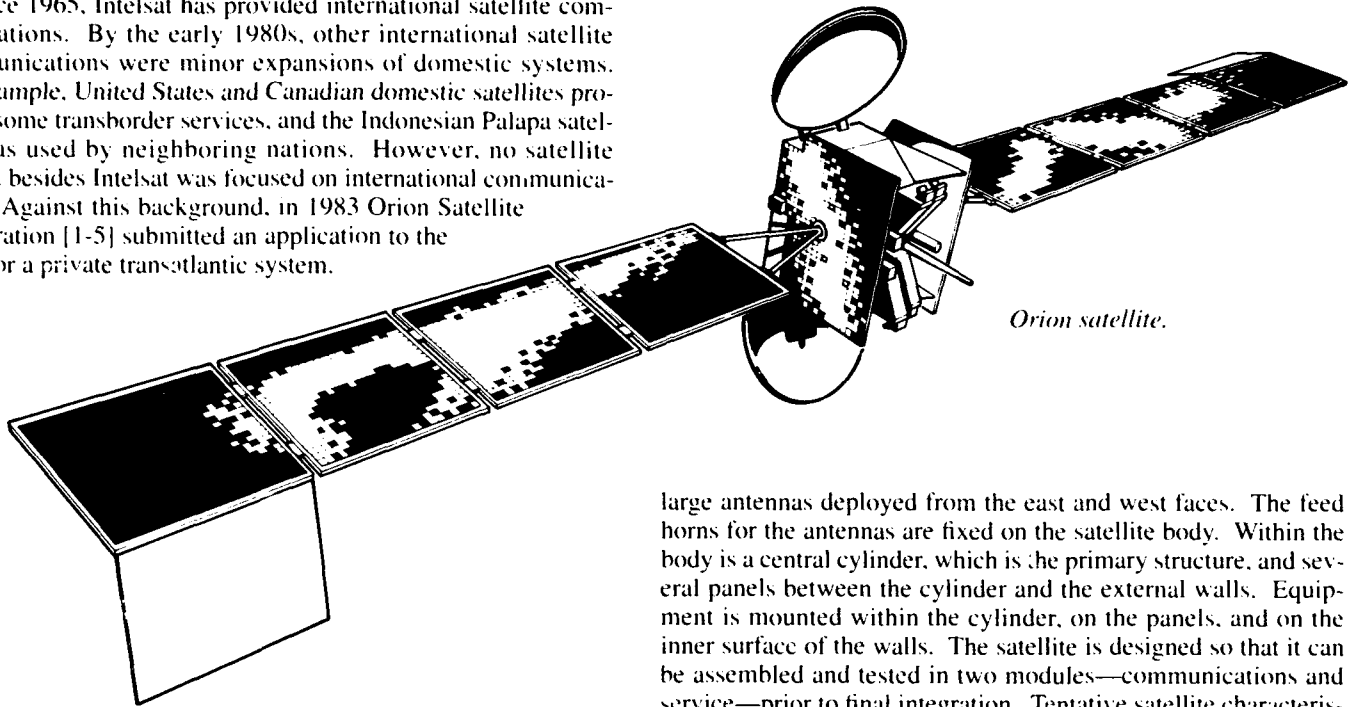


Intelsat K communication subsystem.

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ORION

Since 1965, Intelsat has provided international satellite communications. By the early 1980s, other international satellite communications were minor expansions of domestic systems. For example, United States and Canadian domestic satellites provided some transborder services, and the Indonesian Palapa satellite was used by neighboring nations. However, no satellite system besides Intelsat was focused on international communications. Against this background, in 1983 Orion Satellite Corporation [1-5] submitted an application to the FCC for a private transatlantic system.



Orion satellite.

The Orion application was followed by several others. The reaction within Intelsat was strong opposition, based on the expectation that such systems would divert traffic from the most profitable Intelsat routes, thus reducing its ability to offer economical services worldwide. The concern was particularly strong among the less developed nations, which are the majority of Intelsat members. Within the United States, there was a debate in both the executive branch of the government and in Congress. The debate was between free enterprise and the obligation, as an Intelsat member (even more, the leading founder and biggest investor in Intelsat), not to do anything that would cause technical or economic harm to Intelsat. This obligation is clearly stated in the Intelsat Agreements signed by every member.

By the start of 1985, the United States policy had been settled in favor of free enterprise, yet with some restrictions on what services the private systems could offer. The FCC also required that they complete the technical and economic coordination with Intelsat, although the United States did not promise to refuse authorization to systems, even if Intelsat claimed that it would suffer economic harm.¹

In mid-1985, the first three private systems were given FCC authorization to proceed. Orion's authorization was granted a few months later. Orion completed coordination with Intelsat in 1989 and awarded a contract for satellite construction in the same year. Final FCC approval, to launch and operate satellites, was given in 1990. Ironically, to begin developing a customer base for this satellite, in 1989 Orion began offering international communications services using Intelsat satellites.

The Orion satellites are being built in Europe by a minority investor in Orion Satellite. The satellite is based on the same design used in several other satellites, including Inmarsat II and Telecom 2. Externally, the satellite body is a rectangular box with solar arrays deployed from the north and south faces and two

large antennas deployed from the east and west faces. The feed horns for the antennas are fixed on the satellite body. Within the body is a central cylinder, which is the primary structure, and several panels between the cylinder and the external walls. Equipment is mounted within the cylinder, on the panels, and on the inner surface of the walls. The satellite is designed so that it can be assembled and tested in two modules—communications and service—prior to final integration. Tentative satellite characteristics are listed below:

Satellite

Rectangular body approximately $5 \times 5 \times 8$ ft, span across solar arrays >60 ft
1500 to 2000 lb in orbit
Sun-tracking solar arrays, approximately 2000 W; NiH_2 batteries
Three-axis-stabilized

Configuration

Thirty-four transponders, twenty-eight with 54-MHz bandwidth and six with 36-MHz bandwidth, dual-polarization and dual-beam frequency reuse

Transmitter

11.7 to 12.2 GHz (to North America), 11.45 to 11.7 and 12.5 to 12.75 GHz (to Europe), 11.45 to 11.7 GHz (to Africa)
Thirteen transponder; to North America, seventeen to Europe, four switchable between North America and Africa
15-W solid-state amplifiers, seven sets of five for four redundancy for the 54-MHz transponders, seven for six redundancy for the 36-MHz transponders
Approximately 50 dBW ERP per transponder

Receiver

14.0 to 14.5 GHz
HEMT preamplifiers
G/T varies between 6 and 12 dB/K over coverage areas

Antenna

Two 7-ft dia. parabolic reflectors, each with multiple feed horns, one receive beam and two to four transmit beams per continent, dual linear polarizations

Design life

Twelve years

¹ Additional information is in References 52 through 55 of the Intelsat Systems section.

Orbit

Synchronous equatorial, 37.5 and 47° W longitude

Orbital history

1: launch scheduled late 1992

2: launch scheduled 1993

Atlas II launch vehicle

Management

Developed for Orion by British Aerospace (with subcontractors in France, Holland, the United States, Japan, Germany, Canada)

The communication subsystem design is the result of a trade-off between maximizing performance via narrow beams and minimizing switching complexity via a few broad beams, and weight and power considerations. Fourfold frequency reuse maximizes capacity with good spectral efficiency. The design is eight 54-MHz transponders on one polarization and six 54-MHz plus three 36-MHz transponders on the other polarization of each of two antennas. One antenna provides beams for North America, the other for Europe and portions of Africa. The uplinks all use the same frequencies, but the downlinks use different frequencies, because allocations differ between Europe and the Americas (see Appendix A). Four 54-MHz transponders can be switched between North America and Africa.

The communication subsystem incorporates considerable switching to afford flexibility in routing signals. Communications can be intercontinental or intracontinental. Signals from several uplink beams can be combined in one downlink beam, and a single uplink can be routed to multiple downlink beams. The high G/T and ERP in each of the beams is intended to mini-

mize the ground antenna sizes. Typical diameters will be 4 to 6 ft, although, for very high data rates, sizes up to 33 ft are possible.

The primary market for satellite capacity is expected to be business services, including interactive data circuits, voice, fax, and teleconferencing. Data rates between 56 kbps and 8 Mbps will be common. All signalling will be digital, and some networks will operate with TDMA. The secondary market is thin route domestic services, principally in Africa. Television distribution is another possibility and could be the exception to all-digital signaling.

Satellite development began in 1989. The development contract includes delivery of the satellites in orbit, so the satellite and launch vehicle contractors bear the risks in launching. The two launches are scheduled for late 1992 and mid-1993.

* * * * *

1. C. J. Vizas and W. L. Morgan, "Advanced Transoceanic Satellite Systems," *EASCON Conference Proceedings* (September 1986).
2. A. Hill and S. Shaw, "Orion Stalks Big Game," *Space Markets*, Vol. 5, No. 5 (November/December 1989).
3. D. J. Curtin and S. B. Salamoff, "The Orion Satellite System," Paper 90-0821, *13th AIAA International Communication Satellite Systems Conference* (March 1990).
4. *Satellite Communications* (February 1984), p. 40; (March 1984), p. 20; (September 1989), p. 13; (December 1989), p. 10; (October 1990), p. 19.
5. *Aviation Week & Space Technology* (21 March 1983), p. 28; (30 September 1985), p. 21.

INTELSAT VII

Satellites in the Intelsat system have two roles. The primary satellite in each ocean region provides the basic Intelsat services by connecting all nations in the region. The primary satellite is complemented by a spare satellite, which is used for preemptible services. Other Intelsat satellites provide specialized services, including major path communications (high-density international traffic removed from the primary satellite, so that the primary will have capacity to serve all international paths regardless of traffic density), business communications to small antennas, cable restoration, and domestic leased services.

Every generation of Intelsat satellites through Intelsat VI had been designed to accommodate growth in the Atlantic region primary role, the most demanding in the Intelsat system. When planning began for Intelsat VII in 1985, a new course evolved. The Intelsat VI satellites to be launched, beginning about 1990, would fulfill the demanding primary roles until after the year 2000. The requirement for Intelsat VII [1-13] became replacement of Intelsat V and V-A satellites in the Pacific region primary role and in the specialized services role in all regions. This requirement led to a satellite smaller than Intelsat VI, but with increased flexibility to serve a variety of geographic locations through an increased set of antenna beams interconnected by many switches. The satellite design also emphasizes high performance, to increase the usefulness of smaller earth stations, and higher orbital reliability and lifetimes.

The satellite design is primarily derived from Intelsat V and V-A and the Japanese Superbird. The satellite body is a rectangular box. Within the box, a cylindrical structure carries the primary

loads. The solar arrays are deployed from the north and south faces of the satellite. The two largest antennas are attached to the east and west faces and are deployed in orbit; the other antennas are mounted on the earth-viewing face. The communications and spacecraft equipment is mounted on the insides of the satellite's body panels and on a few secondary panels. Details of the satellite and its payload are as follows:

Satellite

Rectangular body, 8.8 × 8.6 × 7.9 ft, 71.7-ft solar array span, 15.3 ft tall including body and antennas, 26.1 ft across large antennas. Approximately 4200 lb in orbit, beginning of life, 3200 lb without fuel.

Sun-tracking solar arrays and NiH₂ batteries, 3970 W minimum after 10.9 years.

Three-axis stabilization using momentum wheels and magnetic torquers, antenna pointing accuracy ±0.25 deg.

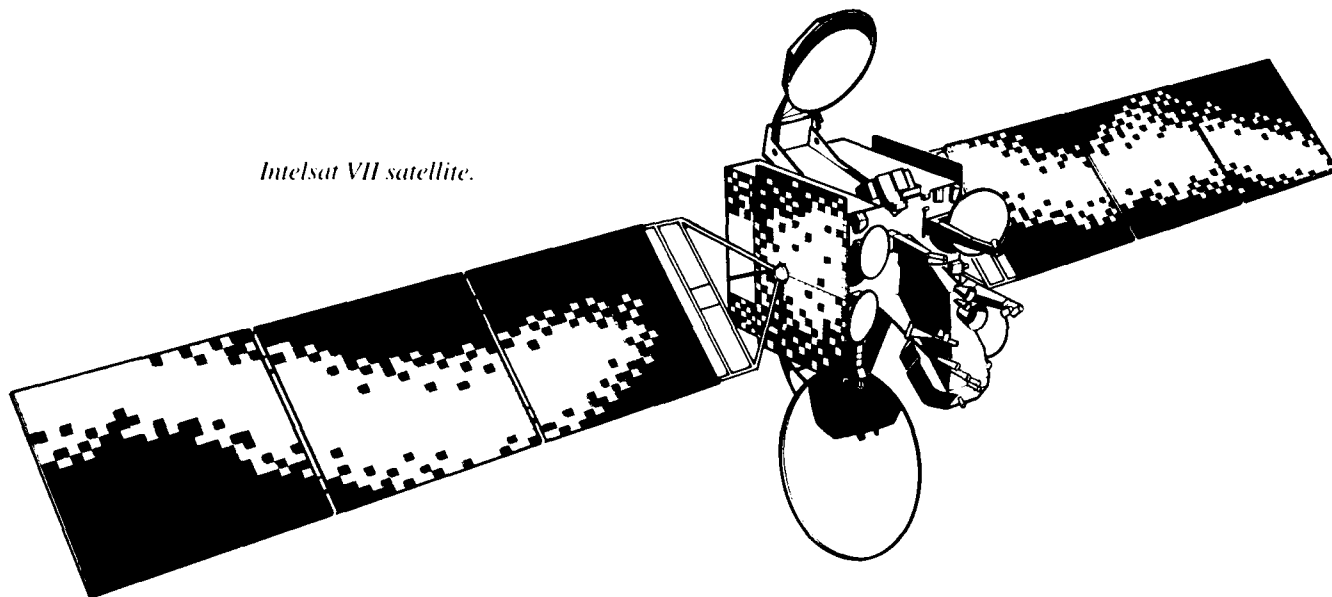
Unified bipropellant propulsion for apogee maneuver and on-orbit use.

Configuration

4/6 GHz: Thirty uplink channels combined into twenty-six downlink channels with 34- to 77-MHz bandwidth, single conversion, dual-beam and dual-polarization frequency use.

11-12/14 GHz: Twelve uplink channels combined into ten downlink channels with 34- to 112-MHz bandwidths, double conversion, dual-beam frequency reuse.

Intelsat VII satellite.



Capacity

Nominal capacity in a typical operational configuration is 18,000 two-way voice circuits (90,000 with full use of digital circuit multiplication techniques) plus three TV transmissions

Transmitter

4/6 GHz: 3704 to 4198 MHz

Global and spot beams: six 16-W solid-state amplifiers for four 36-MHz bandwidth repeaters, three 30-W solid-state amplifiers for two 41-MHz bandwidth repeaters

Hemispheric beams: seven 30/20-W solid-state amplifiers for five repeaters (beam 1/beam 2)

Zone beams: seven 16/10-W solid-state amplifiers for five repeaters (zone 1/zone 2)

ERP (specified minimum): 26/29 dBW (global beams, 36/41-MHz bandwidth), 33/36 dBW (spot beams, 36/41-MHz bandwidth), 33 dBW (hemispheric and zone beams)

11-12 GHz: 10.954 to 11.191 GHz (band A), 11.458 to 11.694 GHz (band B), 11.704 to 11.941 GHz (band C), 12.504 to 12.741 GHz (band D); repeaters (1,2), (3,4), (5,6) independently switchable to bands A or C on one of Spots 1 and 2, to bands A or D on the other, to bands A, C, or D on Spot 3; repeaters (7-9), (10-12) always on band B

Seven 35-W TWTAs for five repeaters interconnected with eight 50-W TWTAs for five repeaters to form fifteen for ten redundancy

ERP (specified minimum): 45.4/43.4/46.7/44.6 dBW (Spot 1), 44.5/41.4/45.8/42.6 dBW (Spot 2), 44.1/41.2 dBW (Spot 2 + 2A), 46.0/43.0/47.5/44.5 dBW (Spot 3), each for 35 W, inner coverage/35 W, outer coverage/50 W, inner coverage/50 W, outer coverage (35 W not used with Spot 2 + 2A)

Receiver

4/6 GHz: 5929 to 6423 MHz

Six receivers with four active for global and spot beams, six receivers with four active for hemispheric and zone beams; HEMT preamplifiers, 1.8-dB receiver noise figure

G/T (specified minimum): -11.5 dB/K (global beams), -3.0 dB/K (spot beams), -8.5 dB/K (hemispheric beam 1), -7.5

dB/K (hemispheric beam 2), -6/-6/-9 dB/K (zone beam 1 with zone α /zone δ /zones $\alpha + \delta$), -4/-4/-7.5 dB/K (zone beam 2 with zone β /zone γ /zone $\beta + \gamma$)

11-12/14 GHz: 14.004 to 14.494 GHz

Five receivers with three active, FET preamplifiers, 3.5-dB receiver noise figure

G/T (specified minimum): +4.5/+1.5 dB/K (Spot 1), +2.5/-1.0 dB/K (Spot 2), +0.5/-3.0 dB/K (Spot 2 + 2A), +3.8/+0.8 dB/K (Spot 3), each for inner/outer coverage

Antenna

4/6 GHz: Two global coverage horns, one transmit, one receive; 18-deg beamwidth; 16.8-dB gain; dual circular polarizations

One 28-in. dia. parabolic reflector for the spot beam; 6-deg beamwidth; 24.5-dB transmit gain, 24.8-dB receive gain; dual circular polarizations; steerable to any point on the earth

One 96-in. dia. (transmit) and one 62-in. dia. (receive) parabolic reflector for hemispheric and zone beams; 110 feed horns (transmit), 114 feed horns (receive); when the satellite is upright, hemispheric beam 1 is west and beam 2 is east, zone beam α is northwest, beam β is northeast, beam γ is southwest, and beam δ is southeast (zone 1 is $\alpha + \delta$, zone 2 is $\beta + \gamma$); when the spacecraft is inverted, each compass direction is replaced by its complement; zones α and γ overlap hemisphere 1 and zones β and δ overlap hemisphere 2, the zones and hemispheres are on orthogonal circular polarizations, the hemisphere beams are spatially separate, as are the zone beams; minimum interbeam isolation is 27 dB

11-12/14 GHz: three circular parabolic reflectors, two (S1 and S2) shaped to generate elliptical beams; each used for both transmission and reception; one beam and one feed horn (S1, S3), two beams and two feed horns (S2) with the second switched in (2 + 2A) or out; 1.3×2.7 deg/ 1.9×4.3 deg (S1), 2.0×3.5 deg/ 3.0×5.4 deg (S2), 2.0×2.8 deg (S3) inner/outer coverage beamwidth; 33.7/31.5/34.6/31.3 dB gain (S1), 31.6/28.4/32.0/28.5 dB gain (S2), 34.2/32.4/34.8/32.2 dB gain (S3) inner coverage transmit/outer coverage transmit/inner coverage receive/outer coverage receive; each antenna transmits and receives using orthogonal linear polarizations, S1 and S2 use opposite polarizations, S3 is the same as S1 on Satellites F-1 and F-2 and switchable on later satellites; each beam steerable to any point on earth

Design life

10.9 years, with fuel for 12.5 years (Atlas launch vehicle) or 19 years (Ariane launch vehicle)

Orbit

Synchronous equatorial, stationkeeping to $\pm 0.05^\circ$ N-S and E-W

Orbital history

F-1, launch scheduled 1993

F-2, launch scheduled 1993

F-3, launch date uncertain

F-4, launch date uncertain

F-5, launch date uncertain

Ariane launch vehicle for three satellites

Atlas-Centaur launch vehicle for two satellites

Management

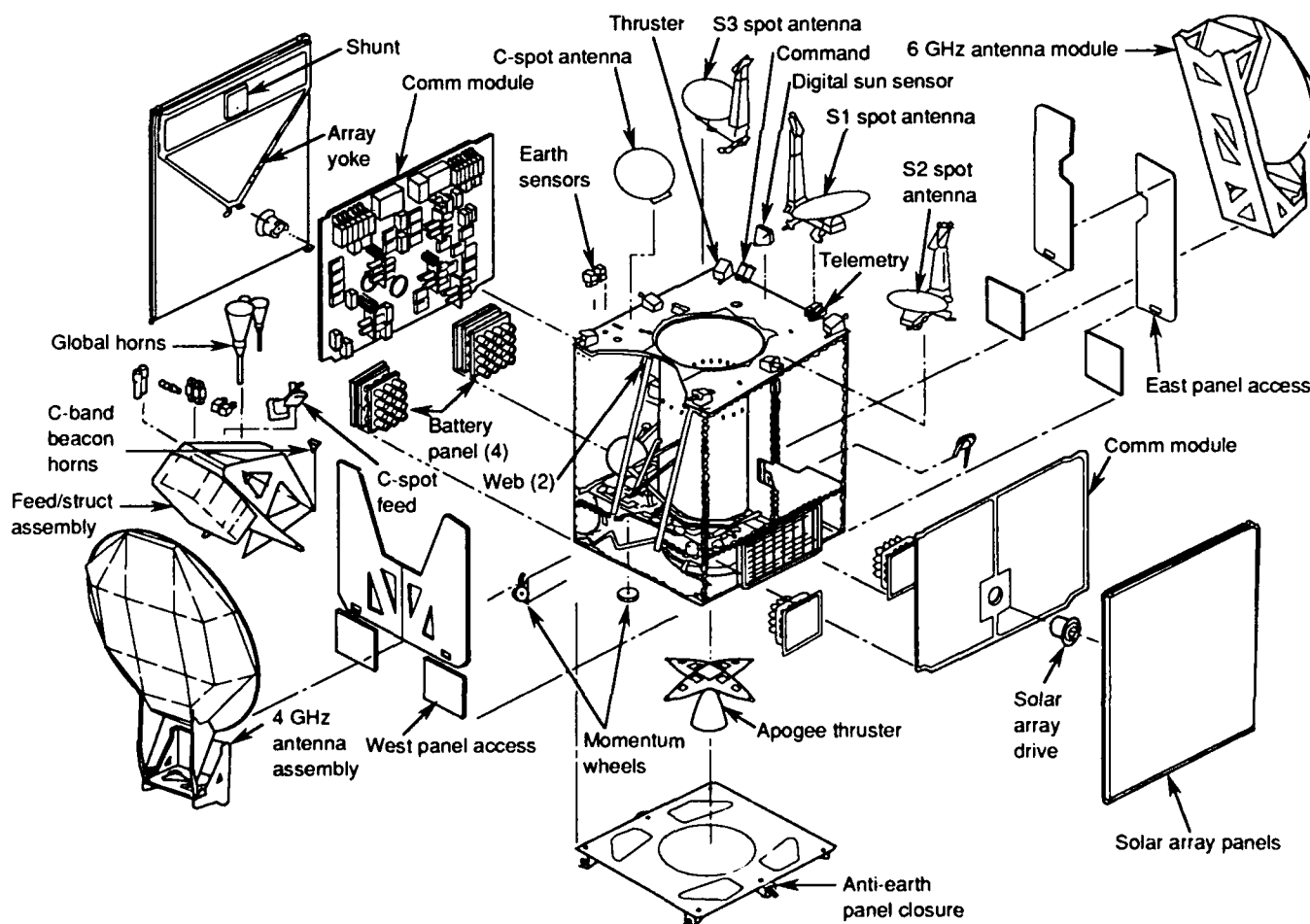
Developed for Intelsat by Space Systems Loral (formerly Ford Aerospace Corporation) with subcontractors from France, Japan, Germany, Italy, the Netherlands, the United Kingdom, Canada, the United States

Operated by Intelsat

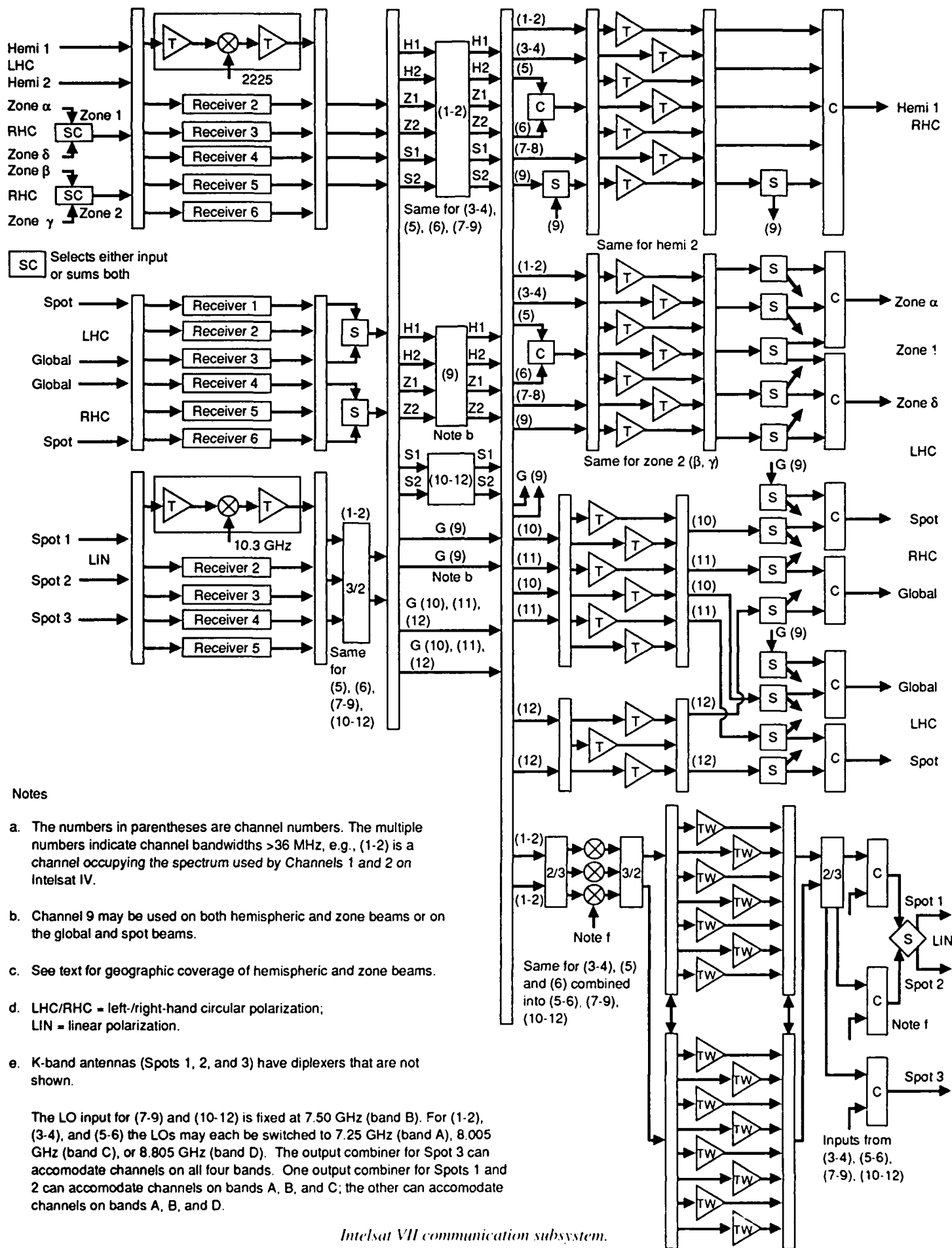
The communications subsystem is similar to those of Intelsat V-A and VI. It has more flexibility in switching individual re-

peaters between the antenna beams, a third K-band spot beam, and the ability to steer each spot beam independently over the entire earth. Compared to Intelsat VI, the communication subsystem is simplified by not including the fast switch matrices for SS/TDMA, by reusing the frequency band only twice in the zone beams (rather than four times), and by not having reconfigurable beam shapes for hemispheric or zone beams. The latter simplification is compensated for by the ability of the spacecraft to invert itself in orbit, thereby reversing the unequal hemispheric beams and zone beams to optimize ground terminal coverage from various orbital locations, as shown in the figure. Intelsat VII is the first Intelsat to have command security.

Because of the attitude inversion capability, new beam designations are required. The two hemispheric beams are Numbers 1 and 2, which correspond to the earlier satellites' west and east hemispheric beams in normal satellite attitude, but become east and west, respectively, when the satellite is inverted. The four zones are designated α , β , γ , and δ and are northwest, northeast, southwest, and southeast when the satellite is in normal attitude. Zones α and δ are combined into zone beam 1; zones β and γ are combined into zone beam 2. Each zone beam repeater is assigned to a zone beam and can be switched to either zone within the beam. The two zones in each zone beam are diagonally opposed, rather than in the same hemisphere, so that both zone beams can support the same hemisphere. The reason for this is that ground



Intelsat VII satellite details.



Intelsat VII communication subsystem.

station traffic is not balanced between east and west for most prospective Intelsat VII orbital locations. The switch matrices in the center of the communication subsystem allow most repeaters to be connected to any one of six beams for reception and independently to any of the six beams for transmission. The six are the two hemispheric beams, the two zone beams, and two K-band spot beams. Further switching in the K-band receiver and transmitter sections allows switching of any repeater to a third K-band beam. The remaining repeaters may each be connected to the C-band global coverage antenna or spot-beam antenna for reception and transmission. K-band Spot beam 2 has an auxiliary feed which may be used to form an additional beam 2A; this capability will be used only when beam 2 is centered on Japan, which will aim beam 2A at the southeast part of Australia.

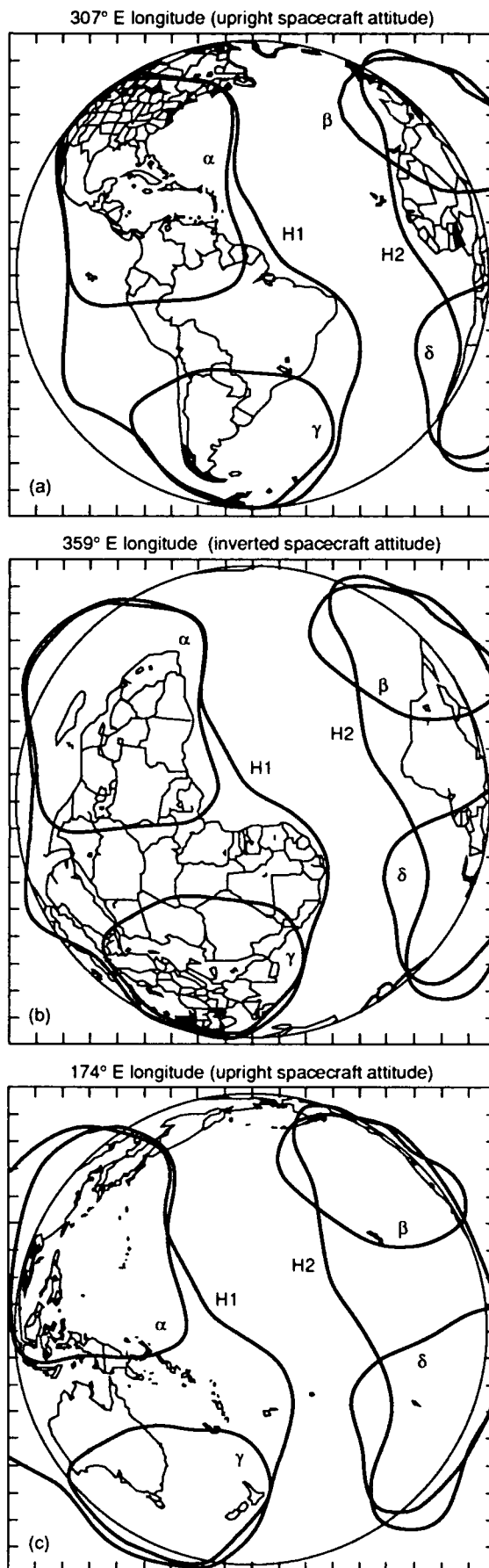
The basic frequency plan is the same as other Intelsats. One difference is the repeaters for channel (5,6), which operate as two separate uplink channels (5), (6) of 34-MHz bandwidth for reception and switching, but are combined into one channel of 72-MHz bandwidth for transmission. The other difference is the regrouping of the upper half of the K-band into two equal channels, each of 112-MHz bandwidth. These repeaters are fixed in the 10.95- to 11.2-GHz downlink band. The repeaters in the lower half of the K-band are switchable between two or three 250-MHz downlink bands to accommodate all available frequency allocations around the world.

The Intelsat VII contract was awarded in October 1988 and covers five satellites. The contract makes a distinction between design life and maneuvering life. The former, specified as 10 years minimum, was negotiated as 10.9 years. The latter, depending on the launch vehicle and the amount of fuel carried on the satellite, can be as long as 19 years. This recognizes the fact that significant capabilities have existed on almost all Intelsats beyond their design life, and that these capabilities are available to all ground terminals if fuel is available for stationkeeping. Furthermore, Intelsat VII is designed to operate beyond stationkeeping life, at up to 3 deg inclination, where it will be useful to ground terminals with tracking capabilities.

The first satellite will be ready for launch by the end of 1992. The remaining four satellites are to be ready at five-month intervals. To guard against launch system failures and outages, Intelsat specified that the satellites be compatible with several launch vehicles. Of the four possibilities, Intelsat then chose two and divided the satellites between them. Satellite growth for payload enhancements is being studied for satellites which might be ordered beyond the five-satellite contract (see the Intelsat VII-A section).

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INMARSAT III

The Inmarsat II satellites, launched first in 1990, will operate into the early years of the next century. The Inmarsat III development is not paced by a lifetime limitation of Inmarsat II, but by its capacity limitation. The number of ships using Inmarsat increases every year, both by choice and gradually due to governments' requirements that ships be equipped for satellite communications. In addition, since 1990, Inmarsat has provided service to airplanes as well as ships. Besides requiring increased satellite capacity, the airplanes also require more of the satellites' power because of their smaller antennas.

Inmarsat III will answer the needs for increased capacity and power. Since the spectrum for mobile satellite communications is limited, the capacity increase will come from the use of five spot beams, in addition to the global beam used on Inmarsat II. The

radiated power in each beam will be about twenty times more than the radiated power in the Inmarsat II global beam.

Inmarsat III will have an L-band receive, L-band transmit transponder to allow mobiles to communicate directly with each other. Such a transponder is not on earlier satellites, requiring mobile-to-mobile communications to be routed through a shore station. Another new payload on Inmarsat III will be a navigation signal transmitter. Its frequency and signal structure will be like those of the United States' Global Positioning Satellite (GPS) and the Soviet Union's Glonass navigation satellites.

Inmarsat III proposals were evaluated in the spring of 1990. In the summer, negotiations with a contractor began in parallel with a five-month technology validation program. The formal contract was signed in February 1991, and the first Inmarsat III launch probably will occur in 1995.

INTELSAT VII-A

At the end of 1990, Intelsat made a decision to develop Intelsat VII-A satellites as a growth version of Intelsat VII. The growth in the communication subsystem includes higher transmitter powers in both C-band (4 GHz) and K-band (11-12 GHz), four more K-band channels which are accommodated by dual polarization frequency reuse on two spot-beam antennas, and greater flexibility in the K-band downlinks.

The satellite design is based upon Intelsat VII; the changes are those necessary to support the higher weight and power of the modified communication subsystem. A fourth panel is being added to each wing of the solar array, which already had been designed to accommodate the fourth panel, and battery capacity is being increased. These changes increase satellite power by about 1 kW. The basic structure is being lengthened, as are the north and south faces of the body. This change will provide space for the additional communications hardware, and for larger fuel and oxidizer tanks. The larger tanks will allow the satellite lifetime to match that of Intelsat VII. Larger heat pipes are being added and other minor changes are being made. The appearance of the satellite will be the same as Intelsat VII except for the slightly longer body and the fourth solar panel on each side.

The only changes in the C-band part of the communication subsystem are an increase in the solid-state amplifier power from 16 to 30 W for four global beam repeaters, new redundancy switching, and a switch to allow connection between a K-band

spot-beam uplink and a C-band global-beam downlink. The changes in the K-band part of the subsystem are more extensive.

The primary architectural change in the K-band communications equipment is the addition of dual-polarization capability to Spot Beams 1 and 2, to form Spots 1X and 2X. Each of the new spots requires a receiver, and another spare receiver is being added, so that the total complement is five active plus three spare receivers. Additional upconverters, switches, filters, and amplifiers allow each new spot to handle two channels, increasing the total number from ten to fourteen. Considerable switching exists to allow several choices of frequencies for these additional channels. Seven TWTAs have been added, and all the TWTAs have been regrouped into two groups of six TWTAs for four channels and two groups of five for three. One group of six and one group of five have 73-W TWTAs; the other groups have 49-W TWTAs. This is an increase from the 50 W and 35 W on Intelsat VII, resulting in about 1 to 2 dB more radiated power. Furthermore, two TWTAs can be combined on command to give 2.2- to 2.5-dB additional output. Another change in the K-band equipment allows channels (1-2), (3-4), and (5-6) to be switched to any of the three downlink bands for Spot Beams 1 and 2 instead of only two choices per beam on Intelsat VII. All three choices are available on Spot Beams 1X and 2X.

Other aspects of the satellite and communication subsystem are as described earlier for Intelsat VII. Two Intelsat VII-A satellites are on contract. They will be launched about 1995.

INTELSAT SYSTEM

Intelsat (the International Telecommunication Satellite Organization) is an organization comprising 120 member nations [1-69]. Its structure is defined in the *Definitive Agreements* that went into effect in February 1973, replacing the *Interim Agreements* that had been in use since the inception of Intelsat in 1964. This change was accomplished by a change from *Consortium* to *Organization* in the full name of Intelsat. Intelsat policy and long-term plans are formulated by the Assembly of Parties, which meets about once every two years and is composed of all governments that are members of Intelsat. Each government has one vote. Basic financial, technical, and operational matters are decided at yearly meetings of telecommunications representatives (either a governmental or a private agency) of the member governments. The Board of Governors meets about five times a year to make decisions on the design, development, operation, and maintenance of the satellites. The Board of Governors is composed of about 28 members. Most members represent countries or groups of countries with relatively large ownership percentages. The remaining members are representatives of geographic regions where countries do not have large ownership percentages; this ensures a worldwide distribution of the board members.

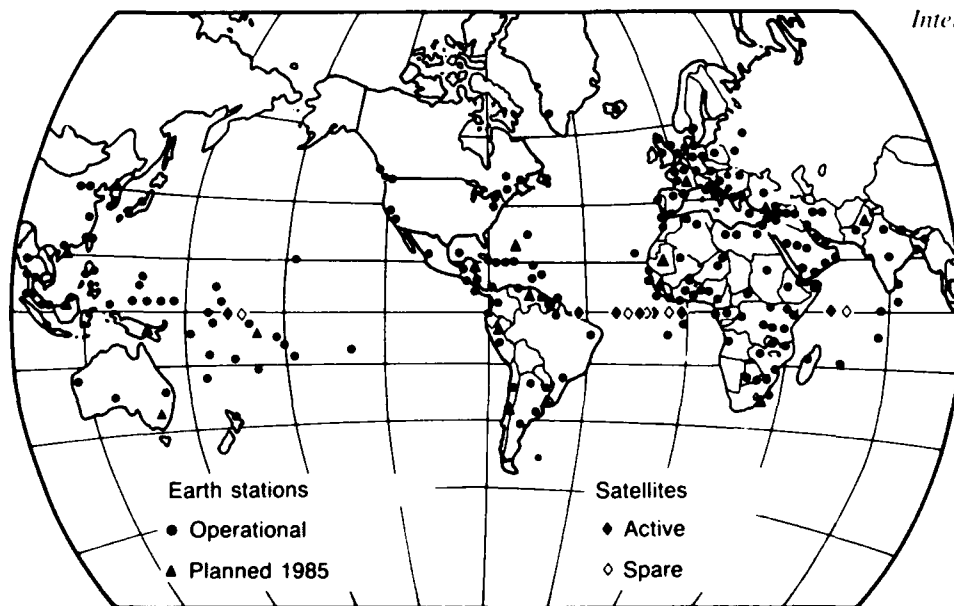
Ownership percentages reflect national investments in Intelsat; these percentages are adjusted to approximate each country's use of the system. When Intelsat began, the United States ownership was over 60%. As more nations began using the system, this percentage dropped and has been 22% to 27% since the late 1970s. Australia, Canada, France, Germany, Italy, Japan, South Korea, and the United Kingdom are the other large owners, with percentages between 2% to 14%.

The Intelsat communication system includes the satellites described earlier, a large number of ground terminals, and a control center. Intelsat owns the satellites, but each member owns its own terminals. The system is composed of Atlantic, Pacific, and Indian Ocean regions. The number of ground terminals has increased yearly since the system became operational in 1965. The number of countries with terminals and the total number of antennas are shown in the figure. The latter numbers are larger, since

some countries have separate terminals operating with different regions of the system, and some terminals use two or three antennas for simultaneous communications through the several active Atlantic region satellites. Only those antennas used in Intelsat's public international network are shown. Many countries also use leased Intelsat satellite capacity for domestic networks. The number of antennas used in these networks increased rapidly since the late 1970s and, by 1983, exceeded the number of antennas shown in the figure. The overall yearly Intelsat system reliability is typically above 99.9%.

Some basic characteristics of the Intelsat ground terminals are given in Table I. Nearly all the terminals now in use correspond to one of these standard types. The standard A terminals have been in use since the 1960s. Although certain features are standard, the terminals have significant differences in the amount of electronic equipment they have, which depends on the number, type, and capacity of the communication links that must be handled simultaneously. Their large antenna size was necessary, because the early satellites (through Intelsat III) were power limited. Thus, system capacity was a function of ground antenna gain, so large antennas were used. Beginning with Intelsat IV, the satellite power limitation decreased. Therefore, Intelsat adopted a specification for the smaller standard B terminal. The objective of standard B is to provide a lower cost terminal for nations with moderate traffic requirements (typically not more than 24 voice circuits). Although the terminal cost is lower, the per circuit satellite usage charge is higher for standard B, because of its lower gain. Standard B terminals have been in use for over a decade, but they number only one-third as many as standard A. In 1986, because of the continuing increase in satellite performance, Intelsat reduced the standard A gain requirements, allowing a smaller antenna diameter.

The standard C terminals communicate with the 11- and 14-GHz transponders first used on Intelsat V satellites. At these frequencies, rain attenuation is significant and is accounted for in the terminal specification. Some standard C terminals use two antennas separated by ten to twenty miles in order to overcome rain



Intelsat system.

Table 1. Intelsat Standard Terminal Characteristics

TERMINAL TYPE	A	B	C	D1, D2	E1, E2, E3	F1, F2, F3	G, Z
Use	International public communications (medium to high capacity)	International public communications (low to medium capacity)	International public communications (medium to high capacity)	International public communications (very low to low capacity)	Business services (domestic or international)	Business services (domestic or international)	G: International private networks (via leased transponders) Z: Domestic networks (via leased or purchased transponders)
Frequency band	C ^a	C	Ku ^b	C	Extended Ku ^c	C	C or Ku
Antenna diameter	15-18m (49-59 ft) ^d	10-12m (33-39 ft)	17-18m (56-59 ft) ^d	4.5-5, 11-13m (15-16.5, 36-44 ft)	3.5, 5.5, 8m (11.5, 18, 26 ft)	4.5-5, 7-8, 9-10m (15-16.5, 23-26, 29.5-33 ft)	
G/T (minimum)	35 dB/K ^d	31.7 dB/K	greater of 37 dB/K + L ₁ ^e or 29.5 dB/K + L ₂ ^e	22.7 dB/K, 31.7 dB/K	25, 29, 34 dB/K	22.7, 27, 29 dB/K	Selected by network operator
Types of transmissions	FDM/FM, CFDM/FM, SCPC/QPSK, SCPC/CFM, TV/FM, TDMA	CFDM/FM, SCPC/QPSK, TV/FM, QPSK/FDMA	FDM/FM, CFDM/FM, TDMA	SCPC/CFM	QPSK/FDMA	QPSK/FDMA	Selected by network operator
Sidelobes	$\leq 32-25 \log \theta$ dB ^f (1° ≤ θ ≤ 48°) ≤ -10 dB (θ > 48°)	Same	Same	Same ^g	Same	Same ^g	Same ^g
Polarization ^h	Circular	Circular	Linear	Circular	Linear	Circular	Circular (C-band) Linear (K-band)

^a Transmit 5.925 to 6.425 GHz, receive 3.7 to 4.2 GHz (through Intelsat V); transmit 5.85 to 6.425 GHz, receive 3.625 to 4.2 GHz (Intelsat VI); not all terminals will be equipped for the entire band of frequencies.

^b Transmit 14.0 to 14.5 GHz, receive 10.95 to 11.7 GHz.

^c Transmit 14.0 to 14.25 GHz, receive 10.95 to 11.7 GHz, and 11.7 to 11.95 GHz (Western Hemisphere) or 12.5 to 12.75 GHz (Eastern Hemisphere).

^d Prior to 1986 the A size was 95-105 ft, the C size was 56-59 ft, and the G/T values were higher.

^e L₁ = clear sky attenuation; L₂ = attenuation exceeded 0.017% of a year.

^f Will probably be reduced to 29-25 log θ dB.

^g If 100 > (D/λ) (antenna diameter to wavelength ratio), then the 1° limit is changed to 100 (λ/D).

^h Axial ratio for C-band is ≤ 1.06 (except ≤ 1.3 for D1); for Ku-band ≥ 31.6.

attenuation by space diversity. The standard C terminals are only used by nations with major communication requirements, which already have one or more standard A terminals.

Standard D is a move in the opposite direction. The objective is to provide a terminal of lower cost than standard B for places with very low communications requirements; perhaps only one or two voice circuits per terminal. Standard D came into use in the mid-1980s and has been applied by small island nations in the Pacific, and by some African nations, for communications between their capitals and small cities in rural areas.

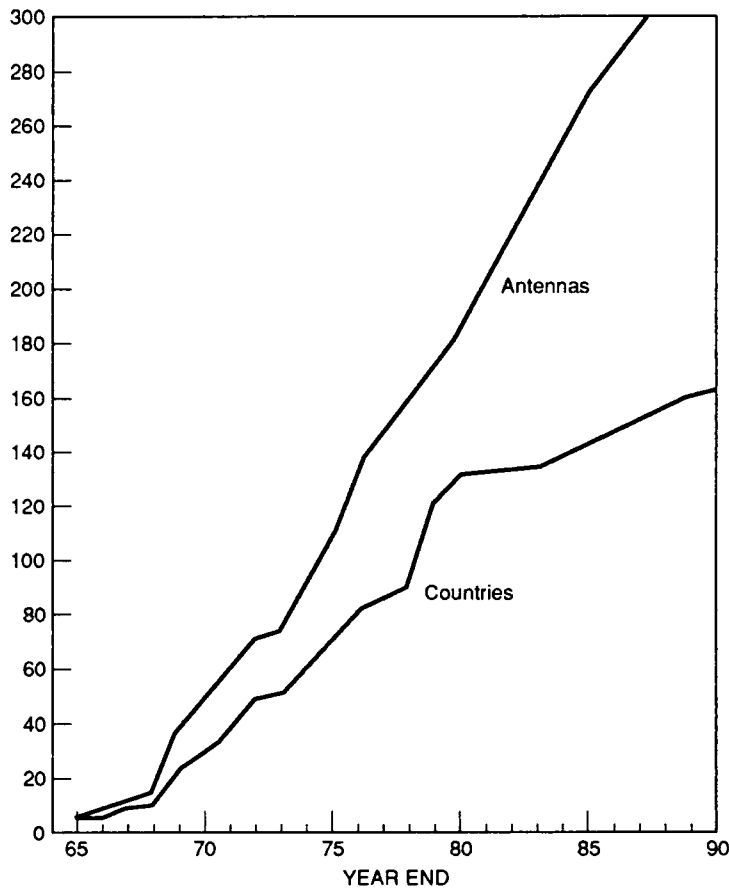
The standard E and F terminals also date from the mid-1980s. The difference between E and F is only the frequency band used and the frequency-dependent specifications. Both are for use with Intelsat Business Service (IBS). These terminals are either located at a specific customer location, or serve multiple customers in a relatively small area, such as one metropolis. This type of customer-specific siting is in contrast to the earlier terminals, which typically serve a whole nation.

Standard G and Z terminals are not used with the Intelsat global, public communications network. Rather, they are used in domestic or binational networks that use leased or purchased

Intelsat satellite capacity. The network operator is free to determine most design and operating characteristics. Intelsat specifies what is necessary to ensure that these terminals do not interfere with other users of the satellite. Many standard Z terminals are in use in domestic networks. Most have relatively small antennas. However, there are some standard A and B terminals that handle communication links in domestic and binational networks in addition to their regular Intelsat links.

The Intelsat system also has six TT&C terminals and four TDMA reference and monitoring terminals. These terminals continually monitor all communication downlinks for satellite problems or evidence of out-of-specification conditions in any transmission. The TT&C terminals monitor satellite health via the telemetry they receive, gather data to be used in orbit predictions, and transit commands. They are located in Maryland, Hawaii, Australia, Italy, Germany, and China. They are under the direction of the Intelsat Operations Center in Washington, D.C. and are linked with it via Intelsat satellites.

Intelsat handles telephone, telegraph, data, and television traffic. Telephone is the major portion of the traffic. In the early years, almost all the Intelsat traffic was voice; but with the growth

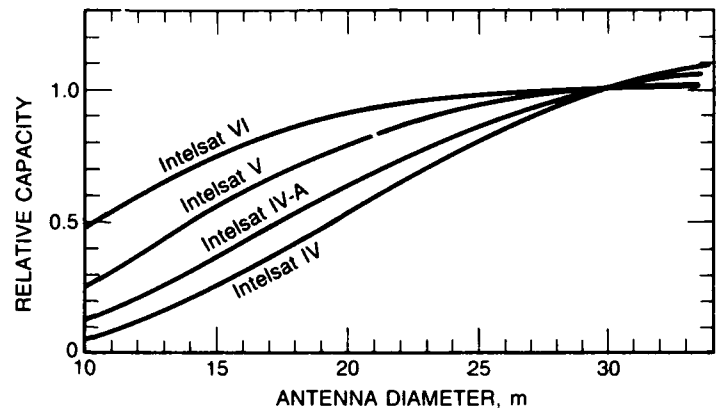


Intelsat ground terminals.

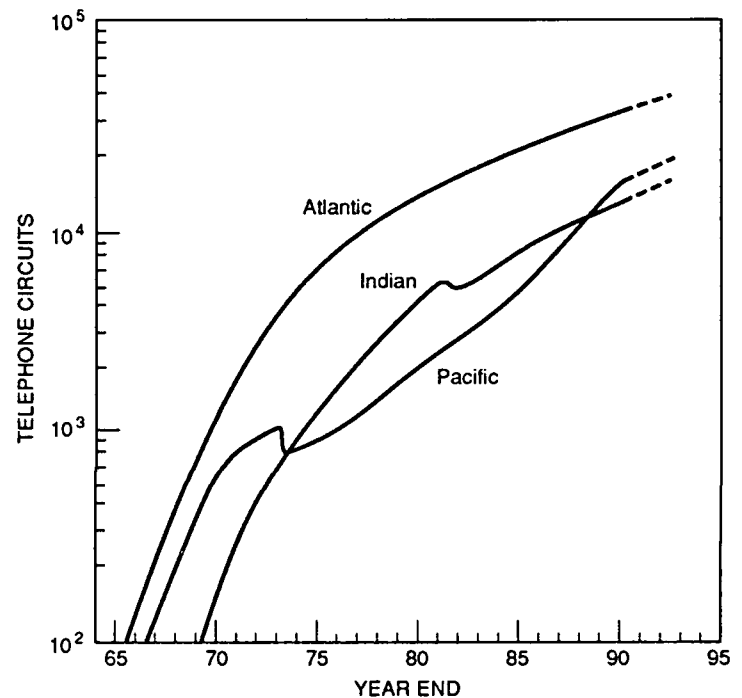
of television transmissions and more recently with a surge in non-voice digital services, revenues from voice traffic are down to about 65% of total revenue. Television accounts for about 10% of the revenues, except in months with events of worldwide interest, e.g., Olympic Games. The Atlantic region has always had the majority of all Intelsat traffic, almost 70% in the early years decreasing to about 60% at present. The Pacific region began earlier than the Indian Ocean region because of earlier satellite availability. However, Indian Ocean traffic rose above Pacific traffic when considerable Hawaiian and Alaskan traffic was transferred to United States domestic systems. In recent years, Pacific traffic has grown quickly, as many small nations have begun to use the system.

This traffic is the international use of the Intelsat satellites. Beginning in 1974, Intelsat leased spare satellite capacity for use in domestic satellite communication systems. Since the end of the 1970s, this service has rapidly increased in popularity. By 1985, over two dozen countries were leasing Intelsat capacity, and about a dozen others had plans to do so. Because of this rapid growth, the 1982 Intelsat changed its policy from providing this service by means of excess satellite capacity to planning future satellite capacity to meet the expected demand, and in 1985 Intelsat authorized satellite transponder sales to member nations. (Leased and purchased satellite capacity is described in a later section.) In addition, in 1982, Intelsat began leasing satellite capacity for international television transmission. Eight nations now participate in these binational transmissions and others are planning new links.

Satellite capacity is allocated to the terminals by preassignment and demand assignment. Preassignments are made by the



Intelsat capacity sensitivity.



Intelsat traffic.

Operations Center for long-duration use, and preassigned links are either single channel per carrier (SCPC) or multiplexed voice circuits in certain standard sizes between 24 and 972 circuits. Television transmissions are preassigned also. Demand assignment, introduced in 1971, uses the SPADE technique (single channel per carrier, pulse code modulation, multiple access, demand-assigned equipment). With this technique, a satellite transponder is divided into 400 channel pairs, each pair handling one voice conversation by means of two SCPC transmissions. Each SPADE terminal has a small computer that selects a channel pair at the time a link is required. Immediately after use, the pair is released and returned to the pool of channels available to all terminals. Demand assignment is used for traffic peaks above preassigned capacity or between terminals with no preassigned circuits.

A number of transmission techniques are used in the Intelsat network. The choice depends primarily on the type and quantity of information to be transmitted, and secondarily on the types of ground terminals used. When Intelsat began, the only links were between a few large ground terminals in developed countries. Each link handled multiple voice circuits. Because of the

equipment and experience developed in terrestrial microwave systems, frequency division multiplexing (FDM)/FM became the early Intelsat transmission standard and is still used on many links. FDM/FM transmissions occur at one of several specified capacities (e.g., 24, 60, ..., 792, 972 voice circuits), each with a satellite bandwidth allocation. All except the largest transmission share satellite transponders by FDMA.

SPADE transmissions are SCPC/QPSK/FDMA. The same transmission format, except with preassignment, is commonly used by standard B terminals, which usually do not have sufficient traffic for the multiple voice circuit FDM transmissions. The SCPC data rate is 64 kbps, conveying either a single voice circuit or a single digital data circuit or multiplexed lower rate data circuits.

With increasing traffic, some standard B terminals were outgrowing the SCPC technique on some links. FDM/FM with companding (CFDM/FM) has been introduced, beginning in 1983, on selected links between both standard A and B terminals. The signal quality improvement due to companding partially offsets the lower gain of standard B terminals.

Television transmissions use FM. At first, and continuing at present, a single TV/FM signal was assigned to a 36-MHz satellite transponder. More recently, for more efficient use of satellite capacity, two TV/FM signals may share a transponder.

As the number of countries that use Intelsat increased, the diversity of routings multiplied. As a result, the percentage of links requiring high-capacity FDM/FM carriers decreased, and the number of low-capacity carriers increased. This reduced the effective satellite capacity, which drops as the number of FDMA carriers per transponder grows. Therefore, in 1978, Intelsat began field tests with TDMA, which provides more capacity than FDMA for the projected traffic loading on many Intelsat transponders.

Since 1981, there has been limited operational use of TDMA on Intelsat V satellites. The transmission rate is 120.8 Mbps and uses 72-MHz bandwidth transponders. Intelsat V-A satellites have some changes to provide better response to TDMA transmission as system use increases. Full operational use of TDMA began in 1985. Its effectiveness will increase as the Intelsat VI satellites are launched, because these satellites have a dynamic switching capacity, which can reconfigure the antenna beam interconnections on a TDMA burst-to-burst basis (SS/TDMA) to maintain a high level of connectivity between TDMA ground stations in different beams. With these satellites, about half of Intelsat's traffic will use TDMA by the early 1990s. Digital speech interpolation (DSI) will be used on TDMA voice circuits to provide up to 2-1/2 times more circuits per transponder than non-DSI FDMA transmissions.

In addition, the data rate per voice circuit is being reduced from 64 kbps to 32 kbps using an adaptive voice encoding technique; this provides another factor of 2 improvement in efficiency of transponder use.

To make use of these benefits of digital transmission on links not requiring the very high TDMA rate, Intelsat introduced the Intermediate Data Rate (IDR) service in 1984. The IDR links use QPSK modulation, information rates between 64 kbps and 44.7 Mbps, error correction encoding, and share transponders by means of FDMA. The IDR is used by both large and small terminals.

Intelsat Business Service (IBS) also began in 1984. The transmission characteristics are the same as IDR, except that the max-

imum data rate is 8.4 Mbps. The difference is that IBS is for private communications via earth terminals at customer sites or in a nearby city, whereas IDR is for public communications via multiuse earth terminals at one or a few locations per country. The standard E and F terminals are primarily for IBS; IDR is used by standard A, B, and C terminals as well as E and F.

Intelnet is another digital service set up in the mid-1980s. It is for low rate (1.2 to 128 kbps) transmissions to or from small terminals (2- to 8-ft dia.). These small terminals communicate with larger terminals, called hubs. The modulation is either BPSK or QPSK, and the multiple access is either by FDMA or code division multiple access (CDMA).

Vista is a service for very low capacity voice requirements, typically one or two circuits per location. It uses standard D terminals with SCPC/compressed FM/FDMA signalling.

Intelsat was conceived as a single, global communications network open to use by all nations, and this principle is included in its fundamental Agreements. Everyone agrees that Intelsat has been successful in accomplishing this. Up to 1988, its only competition had been Intersputnik, a Soviet bloc system that uses Soviet satellites. In addition, intercontinental telephone calls, but not television or high-speed data, may be routed by means of either Intelsat or undersea cables.

Along with the deregulation of United States domestic communications in the 1980s, advocates of free enterprise and competition called for alternative satellite systems for intercontinental communications. Besides a basic free enterprise philosophy, these advocates say that there are communication needs not fulfilled by Intelsat. In response, Intelsat developed a number of new services. More fundamentally, Intelsat argues that the proposed competitive satellites would *skim the cream* from the largest links, which would have consequent negative economic impacts on the many lesser developed countries that use Intelsat. The focus of the debate was several satellite systems proposed in applications filed with the FCC in 1983 and 1984.

Intelsat's Definitive Agreements specify that all member nations must coordinate international satellite links with Intelsat to ensure that they pose no technical or economic harm to the system. Many international links have been coordinated with Intelsat. Examples are United States-Canadian links by means of the domestic satellites of the two countries, and the Eutelsat system for intra-European communications. However, the reaction within the Intelsat staff and membership to these proposals was that they have the potential for significant economic harm and thus could not pass the test for coordination. The United States Government, aware of its obligation as an Intelsat member, and under pressure from Intelsat, studied the situation. The conclusion, in 1985, was a policy that private systems could be allowed to compete with Intelsat, but only for certain types of communications and with certain conditions.

On the basis of this policy, between mid-1985 and early 1986, the FCC granted conditional authorizations to six applicants. These conditional authorizations required the applicants to complete an agreement with a communications entity (usually a government agency) in at least one foreign country and to complete the Intelsat coordination process. In addition, these private international systems were restricted to serving private communications links not interconnected with the public switched network and to providing all services under long-term leases. The first of these systems began operation in 1988 in the Atlantic region. They are described in foregoing sections.

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INMARSAT SYSTEM

In 1972, the Intergovernmental Maritime Organization (IMO) began serious studies of an international maritime satellite system for which it had issued a statement of requirements in 1970 [1-36]. These studies covered institutional, operational, technical, and economic aspects of the system. The primary benefits of such a system, relative to terrestrial radio links, are higher quality, fewer delays, more reliability and privacy, and higher data rates for communications between commercial ships and the international public communication networks. Provisions for handling distress messages are included. In addition, the possibility of providing a position determination service was studied.

IMO has about 80 member nations, of which about 20 were active in the initial studies. In April 1975, IMO convened an international conference to begin establishing the system; 48 nations were represented. It was unanimously agreed that such a system is necessary and that a new organization—the International Maritime Satellite Organization (Inmarsat)—should be formed to operate the system. In 1976, the Inmarsat Convention and Operating Agreement were opened for ratification by interested governments, and an international preparatory committee was established to work on technical, economic, marketing, and organizational matters.

The Inmarsat Convention entered into force in July 1979. The first membership of Inmarsat included 26 nations; that number increased to 64 by spring 1991. The investment share of each nation is related to both the tonnage of ships registered with it and the volume of communications to and from it. (For the United States, these factors are far from equal, as many ships registered in other countries are United States-owned and communicate mostly with the United States.) The investment shares are adjusted yearly to reflect actual use of the system. In recent years, the major shares have been about 25% for the United States, 14% for the United Kingdom, 12% for Norway, and 9% for Japan. Comsat Corporation is the United States representative in Inmarsat.

The Inmarsat organization is very similar to that of Intelsat. The assembly, composed of representatives from all member states, reviews activities and considers long-term policies. The assembly meets once every two years, and each member has one vote. The council meets three times per year and is composed of the eighteen largest members and four representatives of the other members. It provides direction to the Directorate, which carries out the day-to-day activities of Inmarsat. Voting in the council is weighted according to investment percentages.

The Inmarsat system is composed of four segments. Satellites are either leased or owned by Inmarsat. Coast earth stations are owned and operated by Inmarsat members. Some of them provide TT&C facilities for Inmarsat satellites. Ship earth stations are owned (or leased) and operated by shipowners. Network control is exercised from the Inmarsat Operations Control Center in London.

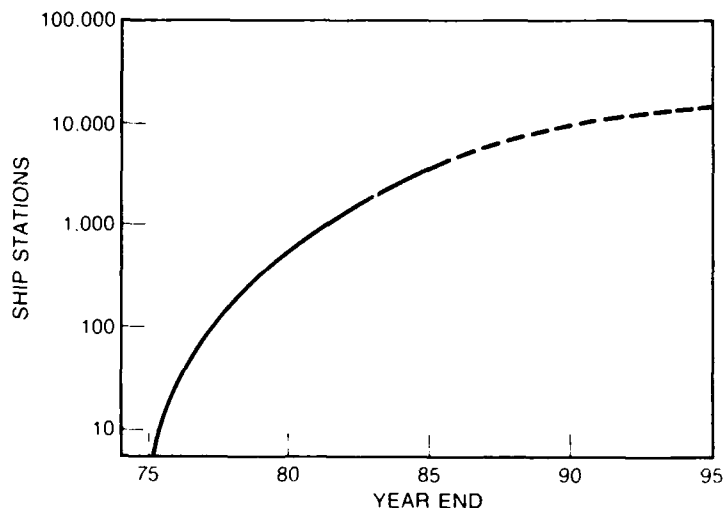
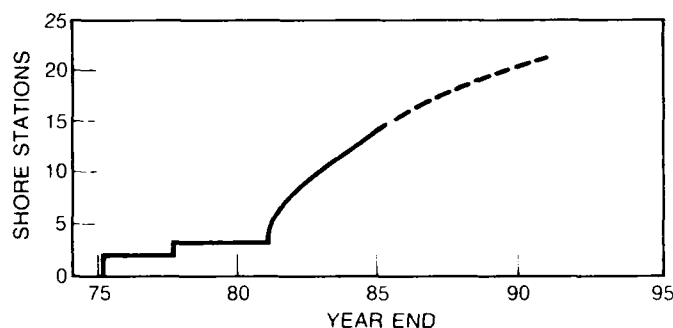
For its initial space segment, Inmarsat chose to lease satellites already existing or in development in order to begin operations as early as possible. Several configurations were studied. The one chosen is a combination of Marisat and Marecs satellites and a maritime communication subsystem (MCS) on the fifth through ninth Intelsat V satellites. On 1 February 1982, Inmarsat took over the use of the three Marisat satellites and began providing service. A few months later, the first Marecs satellite was added to the system and became the primary Atlantic region satellite. The first Intelsat V with the maritime subsystem was launched in

September 1982 and became the primary Inmarsat satellite in the Indian Ocean in January 1983. Marecs B was lost due to a launch vehicle failure. Marecs B2 was launched in late 1984 and became the primary Pacific Ocean satellite in January 1985. In the spring of 1986, the positions of the two Marecs satellites were reversed to place the older satellite in the ocean area with less traffic. Intelsat V satellites have the primary and spare roles in the Indian Ocean. There is also one Intelsat V in each of the other ocean areas. Inmarsat still has the Marisats available in reserve, and it has leased capacity on one for use by land mobile terminals in North America.

In 1990, Inmarsat switched to a four-region system. The operational satellites were Marecs B2 (Atlantic West), Intelsat Vs (Atlantic East and Indian), Marecs A (until June 1991) and an Intelsat (Pacific). The three Marisats remained available as spares. At the end of 1990, the first Inmarsat II satellite was launched. Three more will be launched by the start of 1992 to provide one for each region, with the older satellites as spares.

The growth in shore and ship station population is shown graphically. Numbers prior to 1982 refer to the Marisat system. Shore station locations include the United States, Japan, Norway, the United Kingdom, Singapore, France, Brazil, the Soviet Union, Kuwait, Italy, Denmark, and Greece.

Ship stations are manufactured in various countries and type-certified by Inmarsat. The majority of the standard A type are on large oil tankers, container ships, and bulk cargo ships. Smaller numbers are on research ships, yachts, fishing vessels, and passenger liners. Non-ship applications include antarctic survey



Inmarsat shore and ship stations.

Table 1. Inmarsat Station Characteristics

PARAMETER	SHORE STATIONS	SHIP EARTH STATIONS		
		A	B ^a	C ^a
Transmit frequencies, MHz	6409 – 6425 ^b	1626 – 1648	Same	Same
Receive frequencies, MHz	4179 – 4200 ^c	1530 – 1546	Same	Same
Transmit ERP, dBW	≤ 70	36-37	~ 26	~ 19
Receive G/T, dB/K	≥ 32	– 4	~ – 12	~ – 19
Typical antenna diameter, ft	32-42	3-4	~ 1-1/2	< 1
Ship station capacity		1 voice channel or 2400 bps data ^c	1 voice channel (reduced quality) or 2400 bps data	Telegraphy or 1000 bps data

^a Tentative data

^b Shore stations also have L-band (1650/1550 MHz) transmission and reception for network control and test signals.

^c Modified stations transmit up to 1 Mbps data. Other modifications are being considered to permit multiple simultaneous voice channels.

teams, arctic weather stations, oil production platforms, land mobile units, and a balloon. The terminals are composed of an above-deck unit with a stabilized antenna and some electronics, mounted in a radome, and a below-deck unit with most of the electronics. (Characteristics are given in Table 1.)

The common Inmarsat services are voice, telex, and data. Data may be transmitted at 2400 bps in voice channels, at 56 kbps, or at rates up to 1 Mbps by specially equipped ships. Data rates of 56 kbps and above are ship-to-shore only. Modulation formats include companded FM, QPSK, and FSK.

In 1989, use of standard C terminals began. They are smaller, allowing use on smaller ships, trucks, and aircraft. The data rate does not support voice transmissions but is adequate for messages to and from the mobile user, and position determination and performance monitoring. The transmissions are all BPSK with error correction coding.

In 1982, Inmarsat began investigating service to aircraft. Initial tests were conducted in 1985, and further demonstrations continued through 1988. In 1989, operational service was begun for appropriately equipped planes. The high-speed service accommodates voice or data, while a low-speed service has the standard C capabilities.

After considerable testing and demonstrations of service to land mobile users, operational service was authorized in 1989. The primary application is for long-distance trucking companies, although the service is not limited to them. Land mobile users will have the standard C terminal and will communicate with existing fixed terminals or with new terminals dedicated to launch mobile services.

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INTELSAT LEASES AND SALES

The Intelsat Definitive Agreements, which came into force in February 1973, made provision for leasing satellite capacity for domestic systems [1-15]. The Agreements state that Intelsat space segment capacity not required for the prime Intelsat objective (a global public network) shall be available for domestic services between areas separated by oceans or within areas not linked by terrestrial facilities where there are natural barriers that hinder the establishment of such facilities. The early leases satisfied this condition, but it seems to have been waived for many leases of recent years.

Interest in this use of Intelsat satellites was small for a few years but began to grow rapidly in 1977. Many countries need to improve internal communications and have situations well suited to the use of satellites. However, most do not have the finances necessary to obtain a satellite nor enough traffic to warrant the use of a whole satellite. Leasing of satellite capacity has been the answer to these needs. Intelsat provides almost all the leased capacity because of their many satellites and global deployment. Aside from Intelsat, Indonesia has leased some capacity to its neighbors for a number of years, and, in 1985, the Eutelsat and Arabsat organizations began leasing to their members. Use of such a lease is a low-cost way to establish a domestic satellite system. This arrangement also leads to a quick implementation, since ground

terminals can be delivered much more quickly than satellites. Intelsat leases a specific bandwidth with certain guaranteed satellite performance parameters; ERP is the most significant. Subject to several constraints to prevent interference to other satellite users, the leasing country is free to control its own use of the leased capacity.

Prior to the availability of the Intelsat leases, some countries used the regular Intelsat service for domestic links, treating them as international links. Examples were the use of Intelsat for links within Australia and between the Continental United States (CONUS) and Hawaii, Alaska, and Puerto Rico. In February 1974, the United States transferred CONUS-Hawaii traffic to a leased transponder, which was the first use of an Intelsat lease. This lease was terminated in 1976 when the traffic was transferred to the AT&T domestic satellite. The links to Alaska and Puerto Rico were also transferred to domestic satellites.

Intelsat leases space segment capacity in increments of 9, 18, 36, 54, or 72 MHz. Television requires at least 18 MHz. The service is available on a preemptible or nonpreemptible basis, which relates to the priority of restoration in case of satellite failure. Nearly all the current leases are for preemptible service because of the proven reliability of the satellites (<3 hr outage/yr) and the lower cost (about one-half the nonpreemptible rate). The actual

leases are as small as 9 MHz and as large as several transponders. Several countries began with a lease of one transponder or less and added capacity over several years as they expanded their systems. Over 40 transponders are leased. Some are transponders connected to global coverage antennas, others to hemispheric or spot-beam antennas. The latter have more radiated power, and the lease rate is somewhat higher. Most leased transponders are in the 4/6-GHz band, but the use of 11/14-GHz leases is growing.

Algeria was the first country to use an Intelsat lease for a nationwide system. Operations started in 1975 with 15 terminals and greatly improved the availability and reliability of communications in the 80% of Algeria that lies in the Sahara. Three other countries started using Intelsat leases in 1975. Seven others had started by the end of 1977, and the number has grown since then. Current leases are to:

Algeria	Nigeria
Chile	Pakistan
China (P.R.C.)	Peru
Colombia	South Africa
Cote d'Ivoire	Spain
Denmark	Sudan
France	Thailand
India	United Kingdom
Libya	United Nations
Malaysia	Venezuela
Mozambique	Zaire
New Zealand	

A few countries had leases in the past but terminated them when their traffic was transferred to new domestic satellite systems.

In 1985, Intelsat announced that it would sell transponders that constitute excess capacity on some of their satellites. The purchaser owns the transponder for the remainder of its life, while Intelsat continues to provide satellite control and maintenance. Transponder sales grew quickly; transponders are owned by:

Argentina	Israel
Bolivia	Italy
Central African Republic	Japan
Chad	Niger
Chile	Norway
China (P.R.C.)	Portugal
Ethiopia	Sweden
Gabon	Turkey
Germany	United States
Iran	Venezuela

About 60 transponders have been purchased. Most are 72-MHz bandwidth; about half are in the 4/6-GHz band and half in the 11/14-GHz band. Countries have purchased one to six transponders; several countries have switched from leased to purchased transponders. Gabon, Chad, and the Central African Republic jointly purchased a transponder for shared use.

The reasons for using an Intelsat lease or purchase are varied. Some countries use the satellite to open communications to undeveloped areas where it would be difficult to install terrestrial facilities. Examples are Algeria (desert) and Brazil (jungle). Other countries use the satellite to communicate with points separated by oceans. Examples are Colombia (off-shore island) and Norway (oil-drilling platforms and Arctic islands). Some countries, (e.g., Brazil and Mexico) used the Intelsat capacity as a step toward a national satellite system. Other countries have selected leasing as the quickest or lowest-cost way to expand the national communications network. The United Nations is leasing capacity

to maintain communications between New York, Geneva, and its peacekeeping forces.

The Intelsat leased and purchased capacity is used for television and radio distribution or broadcast, telephony, and telegraphy. In some cases, only one type of traffic is used; in others it is a mix of several or all of these. Capacity per transponder is typically 200 to 500 voice circuits, or one television signal alone or with 50 to 100 voice circuits. Ground antenna sizes, signal quality, and satellite power are three main factors that determine the actual capacity. Ground antenna sizes are between 10 and 45 ft. The choice is up to each country to determine its own balance between cost and capacity. The number of ground terminals in a country varies from 2 to more than 100. In total, over 1000 terminals are in use with leased Intelsat transponders, of which about 400 have the capability for transmitting and receiving; the others are for television reception only.

Voice transmissions between larger terminals are usually FDM/FM/FDMA; QPSK/TDMA is also possible. Voice transmissions to or from smaller terminals are SCPC/FM or SCPC/PSK. Companding is often used. Television transmissions are FM.

Beginning in 1982, Intelsat started leasing capacity for full-time international television transmission. The most common use of this service is for transmission from one country to another; the first use was the United States to Australia. There are also one country-to-multiple-country transmissions and a United States-to-United Kingdom use where the direction of transmission alternates. The countries using Intelsat for international television are the following:

Australia	Philippines
Iceland	Portugal
Japan	United Kingdom
Korea	United States

Originally, Intelsat provided the leased transponders from excess capacity on its spare satellites. This is still true; but in addition, some older satellites not needed as spares have been devoted to leased service. Because of the rapid growth of leases and purchases, Intelsat has now included them in its traffic forecasts to ensure that adequate satellite capacity will continue to be available. In addition, Intelsat has studied the possibility of developing satellites optimized for leased services.

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MILITARY SATELLITES

The first communication satellite experiments were conducted by the Army in 1958. Since then, the Department of Defense (DoD) has continued to develop technology and deploy operational satellites. The various communication satellites developed by DoD are described as are programs of the North Atlantic Treaty Organization (NATO) and the British Ministry of Defence (the Skynet satellites). The Defense Satellite Communications System (DSCS) is also described. The satellites developed by the MIT Lincoln Laboratory for DoD (the LES series) were described earlier. The French and Spanish military satellite communications programs are described later, since they share satellite resources with commercial programs. Also, several of the Soviet satellites described later are used for military communications.

Within the United States, government policy is to establish and maintain distinct military communication satellite systems to

satisfy unique and vital national security needs that cannot be met by commercial facilities. On the other hand, the government will use commercial satellites whenever links of the required type and quality can be obtained in a timely manner at reasonable cost. In general, military command and control circuits are routed through military satellites, but administrative and logistics circuits may use commercial satellites. Differences between military and commercial systems occur because of unique military requirements such as protection against jamming, secure command and telemetry links, flexibility to rapidly extend service to new regions of the globe and to reallocate system assets, hardening of satellites and terminals to resist attacks, and satellite operation continuing through lengthy periods (e.g., several weeks) without command and telemetry support.

IDCSP

No United States military communication satellites were launched between October 1960 (Courier 1B) and June 1966. Courier was a relatively simple program for early experimental use. Concurrently, in April 1960, the Advanced Research Projects Agency (ARPA) undertook the Advent program [1-3] to provide an operational military communication satellite. Advent was to be a three-axis-stabilized, stationkeeping, synchronous altitude satellite with sun-oriented solar arrays and an earth coverage antenna. The communications equipment was to have four repeaters, each with a capacity for 12 one-way voice links or one spread-spectrum voice link. In addition, a secure command system was intended. A number of problems resulted because the concept was far beyond available technology. The satellite weight grew while the Centaur launch vehicle program slipped. After several major reviews, the program was canceled in May 1962. At that time, two programs were recommended. One was to use proven technology to develop simple satellites to be placed in random polar orbits at an altitude of about 5000 miles. The satellites were to be launched seven at a time by means of the proven Atlas-Agena launch vehicle. The second program was for later deployment of synchronous altitude stationkeeping satellites. The programs later were referred to as the Initial and Advanced Defense Communication Satellite Programs (IDCSP and ADCSP) [4-7].

IDCSP did not proceed quickly because of several nontechnical factors. One delay was caused by lengthy discussions with Comsat Corporation concerning whether or not they could provide the satellite services required by DoD. By the fall of 1964, when IDCSP entered the final design and fabrication phase, the Titan IIC appeared to be a feasible launch vehicle. Therefore, the satellite designs were made compatible with either a medium-altitude polar orbit (Atlas-Agena launch vehicle) or a near-synchronous altitude equatorial orbit (Titan launch vehicle). The commonality requirement was dropped after the first successful Titan IIC launch in June 1965, when it was selected as the IDCSP launch vehicle.

The basic design principle for IDCSP was simplicity. By using spin-stabilized satellites in subsynchronous orbits, neither stationkeeping nor active altitude control was required. The random nature of the individual satellite orbits provided automatic replacement of failed satellites with acceptable outages. No com-

mand system was used because of previous experiences—command system failures terminated Courier and Telstar 1 operations, and command system problems contributed to the cancellation of Advent. Telemetry was not required but was added since performance data would be very useful. Each satellite had two TWTs, and an onboard sensor switched from one to the other upon detecting a failure. The two TWTs were of different designs to reduce the chance of a common failure mode. The satellite design details are as follows:

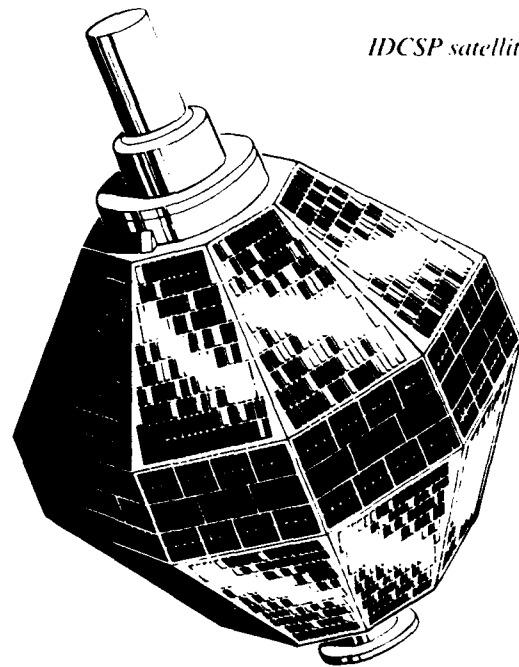
Satellite

Polyhedron, 36-in. dia., 32-in. height

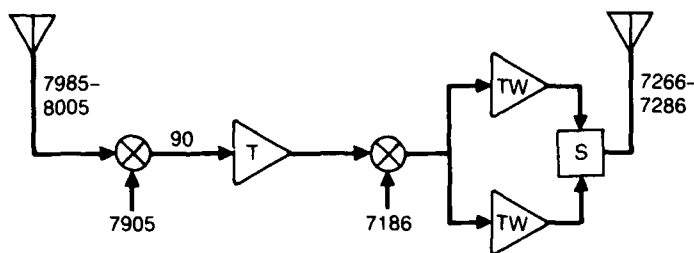
100 lb, GGTS (gravity gradient test satellite) 104 lb, DATS (despun antenna test satellite) 150 lb

Solar cells, approximately 40 W initially (no batteries, no operation during eclipses)

Spin-stabilized, 150 rpm



IDCSP satellite.



IDCSP communication subsystem.

Configuration

One 20-MHz bandwidth double-conversion repeater

Capacity

Two-way circuits: up to five commercial quality voice, or eleven tactical quality voice, or 1550 teletype

Approximately 1 Mbps digital data

Transmitter

7266.4 to 7286.4 MHz

Two TWTs (one on, one standby)

3-W output, 7-dBW ERP maximum

Receiver

7985.1 to 8005.1 MHz

10-dB noise figure

Antenna

Two biconical horns (one transmit, one receive)

28 × 360 deg, 5-dB gain, circular polarization

DATS: electronically despun, antenna elements are mounted on a cylinder placed along the spin axis at one end of the satellite, 10-dB additional gain

Design life

1.5 years required, three-year goal

Orbit

17,800- to 18,700-nmi altitude range

Inclination <1 deg for most satellites

Approximately 30 deg per day longitude drift

Orbital history

1 to 7: launched 16 June 1966

Eight unnumbered satellites lost in a launch vehicle failure
26 August 1966

8 to 15: launched 18 January 1967

16 to 18: launched 1 July 1967

19 to 26: launched 13 June 1968

GGTS: launched with 1 to 7

DATS: launched with 16 to 18

Operating lifetimes (excluding GGTS and DATS):

5: one-year operation before failure

1: one- to two-year operation before failure

2: two- to three-year operation before failure

2: three- to four-year operation before failure

2: four- to five-year operation before failure

2: five- to six-year operation before failure

2: six- to seven-year operation before failure

1: seven- to eight-year operation before failure

6: turned off by the on-board timer after six- to eight-year operation

3: operated nine to ten years

Overall MTBF about six years

Titan IIIC launch vehicle

Management

Developed by Philco (later Ford Aerospace and Communications Corporation) for Air Force Space and Missile Systems Organization (now Air Force Space Systems Division)

Operated by Defense Communications Agency (now Defense Information Systems Agency)

The first IDCSP satellites were launched in June 1966. Additional satellites were launched in 1967 and 1968; two launches had a full load of eight IDCSP satellites and the other had three in addition to three other satellites. In 1967, increasing military activity in Vietnam led to the establishment of an operational communication link using IDCSP. In this link, high-speed digital data were transmitted from Vietnam to Hawaii through one satellite and from there to Washington, D.C. through another satellite.

By the time of the 1968 launch, the system was declared operational and the name changed to Initial Defense Satellite Communication System (IDSCS). The satellites operated for periods ranging from a few thousand to more than 70,000 hr (eight years). The satellites each had a device that was supposed to deactivate them approximately six years after launch. Several satellites were turned off in this manner, although others continued to operate well beyond six years. The overall satellite reliability was much beyond the original expectations; specifically, the actual mean time before failure (MTBF) achieved was more than double the three-year goal for design life. Three of the satellites were still being used in early 1976 to supplement the DSCS II satellites. By mid-1977, only one was still useable.

* * * * *

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TACSAT

The IDCSP satellites and the advanced satellites that were to follow IDCSP were all intended for strategic communications. Strategic communication terminals basically include large antenna fixed or transportable ground stations or large shipborne equipment. Tacsat [1-4] was designed for a complementary function, namely, to operate with small land-mobile, airborne, or shipborne tactical terminals.

The Lincoln Experimental Satellites (LES-1 to -6) were predecessors to Tacsat and were used to investigate various aspects of tactical communications. Strategic military communication satellites typically use frequencies between 7.2 and 8.5 GHz. At these frequencies, directional antennas are required; these antennas have several drawbacks in tactical use. One drawback is the problem of accurate pointing, especially from aircraft. The LES satellites proved that UHF (approximately 300 MHz) communication is possible with terminals that have simple, low-gain (wide-beamwidth) antennas. Tacsat was designed with both UHF and X-band (8 GHz) capabilities and crossover modes (UHF receive and X-band transmit, or vice versa) to permit operation with a wide variety of terminals.

The requirements for Tacsat resulted in a number of design features not found in previous communication satellites. Nearly 1 kW of prime power was required for the high-power transmitters, which necessitated a very large cylindrical body to provide the required solar cell area. Tacsat was spin-stabilized like all previous communication satellites. However, because of the large antenna structure and launch vehicle fairing constraints, it did not spin about the axis with the maximum moment of inertia. This was a potentially unstable condition that was controlled by special stabilizing elements. The stabilization worked in orbit, although at times a 1-deg nutation occurred, apparently the result of destabilizing forces that were greater than expected. The stabilization techniques developed for Tacsat and called gyrostat by the manufacturer were refined and applied to many subsequent satellites. Other design features of Tacsat are as follows:

Satellite

Cylinder, 9-ft dia., 11-ft height (25 ft overall)
1600 lb in orbit, beginning of life
Solar cells and NiCd batteries, 980 W
Spin-stabilized, gyrostat, 54 rpm
Cold gas propulsion for on-orbit use

Configuration

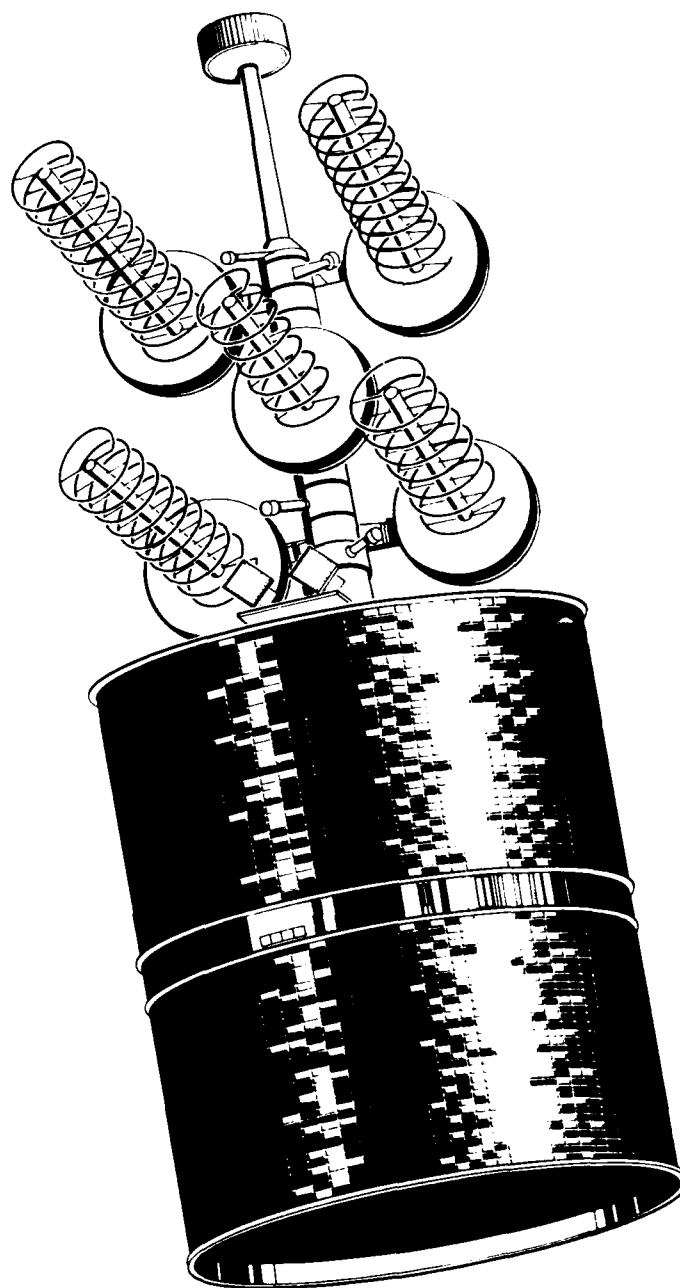
Multiple channels, 50-kHz to 10-MHz bandwidths

Capacity

UHF: about forty vocoded voice or several hundred teletype circuits to a terminal with 0-dB antenna gain
X-band: about forty vocoded voice or 700 teletype circuits to a terminal with a 3-ft antenna

Transmitter

249.6 and 7257.5 MHz
UHF: all solid state, sixteen parallel transistor amplifiers, up to sixteen on at a time (nominal thirteen on), 18.5 W per amplifier, 230 W maximum out of combiner
X-band: three TWTs, two on at a time, 20 W per TWT, 30 W out of combiner



Tacsat satellite.

Receiver

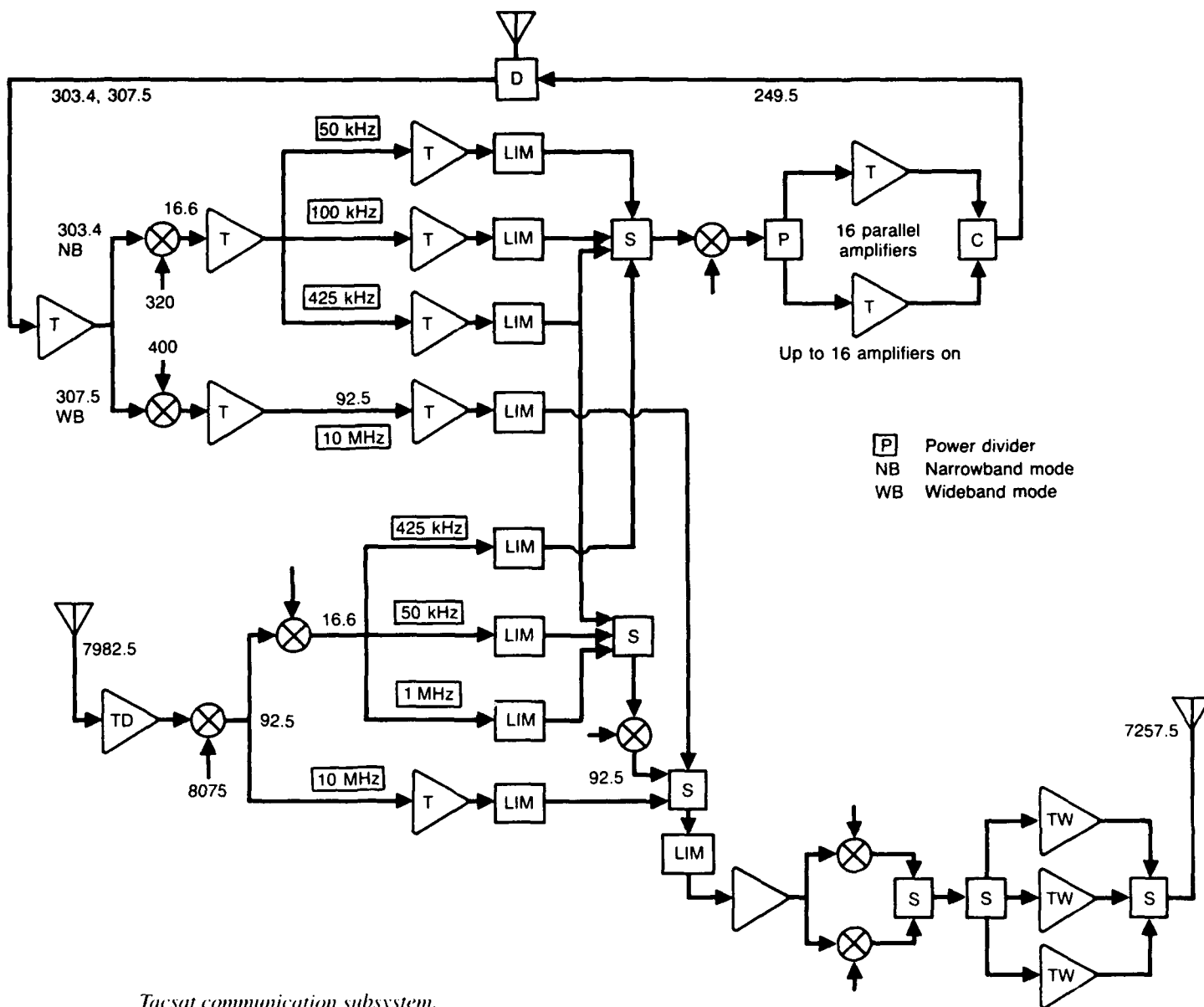
303.4, 307.5, and 7982.5 MHz
UHF: transistor amplifiers, 3.7-dB noise figure
X-band: tunnel diode preamplifier, 6.9-dB noise figure

Antenna

UHF: five bifilar helices, 17.1-dB transmit gain, 17.6-dB receive gain
X-band transmit: horn, 18.4-dB gain, 19-deg beamwidth
X-band receive: horn, 19.3-dB gain, 17-deg beamwidth

Design life

2.4 years estimated life



Tacsat communication subsystem.

Orbit

Synchronous equatorial, approximately 180°W longitude

Orbital history

Launched 9 February 1969

Operated until December 1972

Titan IIIC launch vehicle

Management

Developed by Hughes Aircraft Company for Air Force Space and Missile Systems Organization (now Air Force Space Systems Division)

Operated by Air Force Communications Service

Tacsat was launched in February 1969. Because of funding limitations, no flight model was assembled, and the qualification model was the one launched. On-orbit testing was done with a large variety of terminals, including large ground stations, mobile

ground stations, aircraft, and ships. Some multiple access testing was conducted. Tacsat was used for operational support of Apollo recovery operations, connecting the aircraft, their aircraft carrier, and ground stations. Military use, especially of the UHF band, was extensive. Operations continued until an attitude control failure at the end of 1972.

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SKYNET I AND NATO II

The Skynet (United Kingdom) and NATO satellite programs [1-6] were both a result of a United States invitation to certain nations to participate in the use of United States defense communication satellites. In 1966, the United Kingdom indicated an interest in participation, but the IDCSP satellites could not satisfy their requirements. The primary difference was the need to service both ground stations with large antennas and shipborne terminals with smaller antennas. In late 1966, the United States and United Kingdom signed an agreement whereby the United States would develop satellites that would satisfy United Kingdom needs. The satellites were to be interoperable with the IDCSP system, and the program was initially called IDCSP/A (for augmentation). This program is now called Skynet. NATO decided to participate directly in the use of IDCSP satellites and operated two IDCSP ground stations from 1967 to 1970. That period was used to gain experience prior to operation of a NATO satellite.

The Skynet and NATO satellites were nearly identical and were derived from the IDCSP design, but there were certain notable improvements from IDCSP. The Skynet and NATO satellites were placed into a synchronous orbit and had a stationkeeping capability. They had a despun antenna that provided increased gain, relative to IDCSP, and both 2- and 20-MHz channels. These features permitted operation with both large and small terminals. Also, the satellites were larger than IDCSP satellites and had a command system. The only significant difference between the two satellites was the antenna pattern. The Skynet antenna provided a relatively uniform earth coverage pattern centered at the equator. The NATO antenna pattern was shaped to cover only the NATO nations, from the eastern coast of North America to Turkey. Skynet I and NATO II details are as follows:

Satellite

Cylinder, 54-in. dia., 32-in. height (62 in. overall)

285 lb in orbit

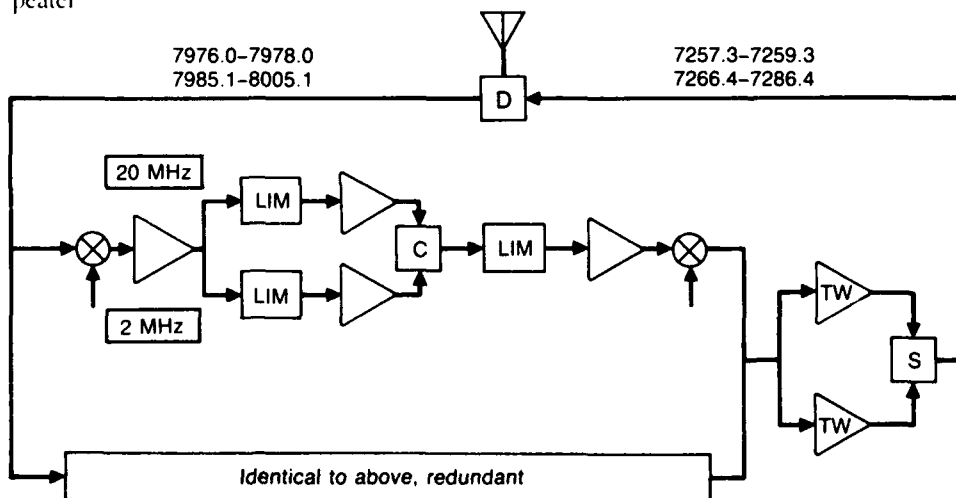
Solar cells and NiCd batteries, 78 W

Spin-stabilized, 90 rpm

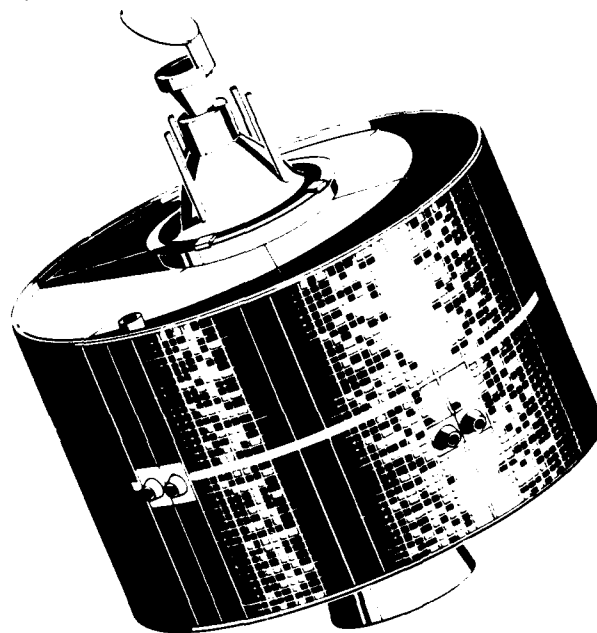
Solid rocket motor for apogee maneuver, hydrazine propulsion for on-orbit use

Configuration

One 2-MHz and one 20-MHz bandwidth double-conversion repeater



Skynet I communication subsystem.



Skynet I satellite.

Transmitter

7257.3 to 7259.3 MHz and 7266.4 to 7286.4 MHz

Two TWTs (one on, one standby), 3.5-W output

Skynet: 14.4-dBW ERP per channel, edge of earth

NATO: 11-dBW (2-MHz channel) and 19-dBW (20-MHz channel) ERP, edge of coverage

Receiver

7976 to 7978 MHz and 7985.1 to 8005.1 MHz

Redundant receivers (one on, one standby)

8.8-dB noise figure

Antenna

Skynet: mechanically despun horn, earth coverage 18.5-dB peak gain

NATO: mechanically despun horn, NATO area coverage (North American east coast to eastern Turkey)

Design life

Five years (three-year mean mission duration)

Orbit

Synchronous equatorial (inclination ≤ 3 deg)

Skynet: $49 \pm 3^\circ$ E longitude

NATO: $18 \pm 3^\circ$ W longitude (IIA), $26 \pm 3^\circ$ W longitude (IIB)

Orbital history

Skynet IA: launched 21 November 1969, operated 36 months

Skynet IB: launched 19 August 1970, apogee motor failure left satellite in synchronous transfer orbit

NATO IIA: launched 20 March 1970, operated 26 months

NATO IIB: launched 3 February 1971, operated until August 1976

Delta launch vehicle

Management

Developed by Philco (later Ford Aerospace and Communications Corporation) for Air Force Space and Missile Systems Organization (now Air Force Space Systems Division), acting for the United Kingdom and NATO

Operated by United States/United Kingdom and United States/NATO

The first Skynet satellite was launched in November 1969 and operated for several years with a variety of terminals. Antenna sizes varied from 42 ft at the master ground station to 3.5-ft shipborne terminals. The second Skynet satellite did not achieve the intended synchronous orbit because of failure of the apogee motor.

The NATO satellites were designated NATO IIA and IIB, with NATO I referring to the period of operations during which the IDCSP satellites were used. NATO IIA and IIB were launched in March 1970 and February 1971. The former was used for communications between NATO headquarters and the capitals of NATO member countries. Planned use with shipborne terminals was delayed, because other traffic occupied nearly all of the satellite capacity. NATO IIB was originally an orbiting spare that was

used in tests of new ground stations. The communications traffic was transferred to it after NATO IIA failed. Communications traffic was transferred to NATO IIIA in April 1976, and NATO IIB was turned off in August 1976.

* * * * *

1. V. W. Wall, "Military Communication Satellites," *Astronautics and Aeronautics*, Vol. 6, No. 4 (April 1968).
2. J. W. O'Neill, "Military Communication and Navigation Satellites," *TRW Space Log*, Vol. 9, No. 2 (Summer/Fall 1969).
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DSCS II

The IDCSP satellites were the Phase I space segment of the Defense Satellite Communication System (DSCS). System testing was undertaken immediately after the first launch in 1966, and the Pacific part of the DSCS was switched to operational status a year later. The experiences of Phase I demonstrated that satellite communications could satisfy certain DoD needs. Therefore, in June 1968, DoD decided to proceed with development of advanced satellites for DSCS Phase II [1-10].

The DSCS II satellites (formerly called the 777 satellites because their development was called Program 777) are significantly different from the IDCSP satellites. The DSCS II satellites have a command subsystem, attitude control and stationkeeping capability, and multiple communication channels with multiple access capability; IDCSP had none of these features. However, the DSCS II design is compatible with modified Phase I ground terminals as well as new terminals specifically built for Phase II.

The Phase II satellites have a dual spin configuration. The outer section (which includes the cylindrical solar array, much of the structure, and an equipment platform) is spun to stabilize the satellite. The inner section (containing all the communications equipment and antennas) is isolated from the outer section by a motor and bearing assembly. The motor despins the inner section so that the antennas are always pointed at the earth. The satellite has four antennas: two parabolic reflectors and two horn antennas. The satellite details are as follows:

Satellite

Cylinder, 9-ft dia., 6-ft height (13 ft overall)

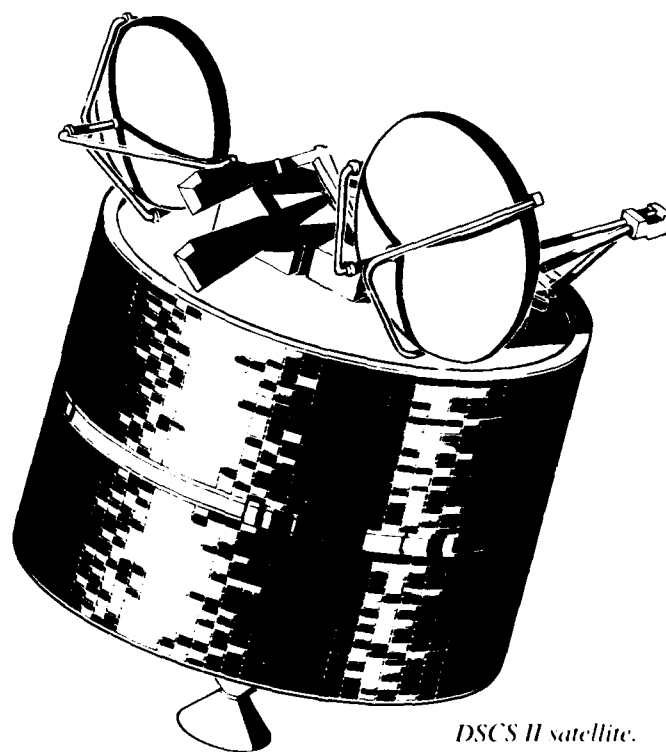
1350 lb in orbit, beginning of life

Solar cells and NiCd batteries, 520 W initially, 388 W minimum at five years

Spin-stabilized, 60 rpm, 0.2-deg antenna pointing accuracy
Hydrazine propulsion for on-orbit use

Configuration

Four channels with 50- to 185-MHz bandwidths, single conversion (see text)



DSCS II satellite.

Capacity

1300 two-way voice circuits or approximately 100 Mbps digital data

Transmitter

7250 to 7375 MHz, 7400 to 7450 MHz, 7490 to 7675 MHz, 7700 to 7750 MHz

Two independent transmitters, one for the two earth coverage channels, one for the two narrowbeam channels; 20-W output per transmitter (40 W for Satellites 13–16)

ERP per transmitter: Satellites 1 to 6:

28 dBW, earth coverage

43 dBW, one narrowbeam antenna

40 dBW, each of two narrowbeam antennas

Satellites 7 to 12:

28 dBW, earth coverage

43 dBW, narrowbeam antenna

31 dBW, area coverage antenna

40/28 dBW, using both narrowbeam and area coverage (50% of power to each)

Satellites 13 to 16:

31 dBW, earth coverage

46 dBW, narrowbeam antenna

34 dBW, area coverage antenna

40/33 dBW, using both narrowbeam and area coverage (75% of power to area coverage)

Earth coverage specified at ≥ 7.5 deg earth terminal elevation angle; narrowbeam and area coverage anywhere within beamwidth

Receiver

7900 to 7950 MHz, 7975 to 8100 MHz, 8125 to 8175 MHz, 8215 to 8400 MHz

Tunnel diode preamplifiers and limiter/amplifiers

7-dB noise figure

Antenna

Two earth coverage horns (one transmit and one receive), 16.8-dB gain at edge of earth

Two narrowbeam parabolas, 44-in. dia., 2.5-deg beamwidth, 36.5-dB gain on axis, steerable ± 10 deg each axis; on Satellites 7 to 16, one antenna has been defocused to a 6-deg beamwidth for area coverage

All antennas mounted on a despun platform and circularly polarized

Design life

Five years (three-year MMD)

Orbit

Synchronous equatorial, inclination < 3 deg

Orbital history

1, 2: launched together 2 November 1971, operated 20 and 8 months

3, 4: launched together 13 December 1973, 3 operated 30 months, moved above synchronous orbit; 4 is experimental, 56°W longitude

5, 6: launched together 20 May 1975, left in low orbit by launch vehicle failure, reentered 26 May 1975

7, 8: launched together 12 May 1977, 7 taken out of service May 1979, 8 taken out of service by 1988, both moved above synchronous orbit

9, 10: launched together 25 March 1978, launch vehicle failure

11, 12: launched together 13 December 1978, 11 was retired, 79°W longitude; 12 is a spare, 72°E longitude

13, 14: launched together 21 November 1979, 13 is a spare, 180°E longitude; 14 is a spare, 65°E longitude

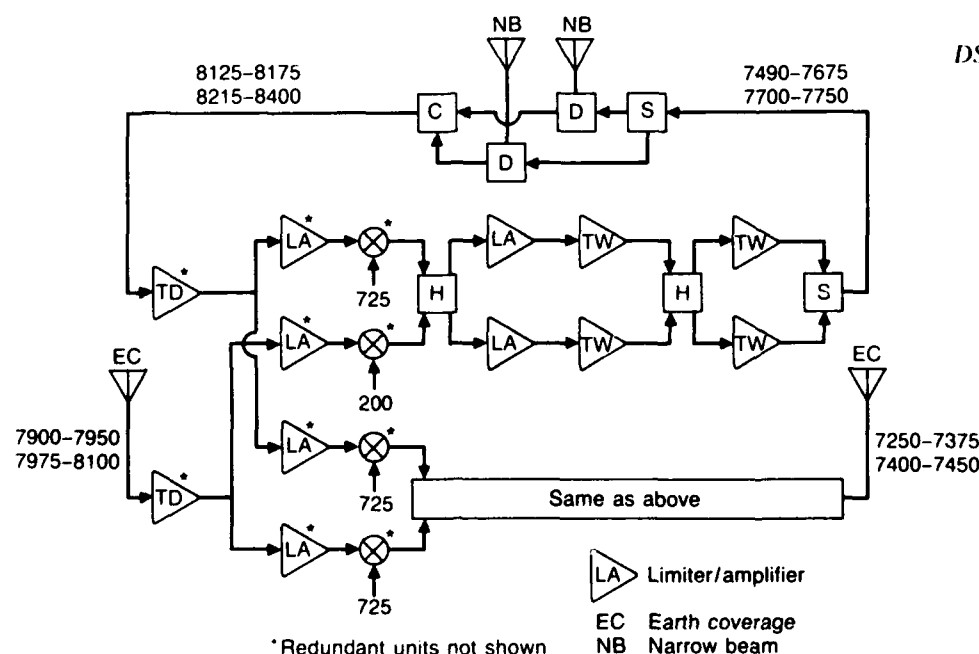
15: launched 1989 with DSCS III-A2, is operational

16: launched 30 October 1982 with DSCS III-A1, is operational, 59°E longitude

Titan IIIC launch vehicle (1–14)

Titan 34D/Transtage (15)

Titan 34D/IUS launch vehicle (16)



DSCS II communication subsystem.

Management

Developed by TRW Systems Group for Air Force Space Systems Division (formerly Air Force Space and Missile Systems Organization)

Operated by Defense Information Systems Agency (formerly Defense Communications Agency) TT&C support by Air Force Satellite Control Facility

The DSCS II communication subsystem has four channels with the following characteristics:

- Channel 1: bandwidth, 125 MHz; receive antenna, earth coverage; transmit antenna, earth coverage
- Channel 2: bandwidth, 50 MHz; receive antenna, narrowbeam or area coverage (on Satellites 7-16); transmit antenna, earth coverage
- Channel 3: bandwidth, 185 MHz; receive antenna, narrowbeam or area coverage (on Satellites 7-16); transmit antenna, narrowbeam or area coverage (on Satellites 7-16)
- Channel 4: bandwidth, 50 MHz; receive antenna, earth coverage; transmit antenna, narrowbeam or area coverage (on Satellites 7-16)

This selection of channels provides the flexibility to handle a wide variety of links and to interface with many different sizes of terminals. The subsystem includes tunnel diode preamplifiers, single-frequency conversion, tunnel diode amplifiers (TDAs) and driver and high power TWTs. The TDAs can be switched to various gains to permit either linear or saturated operation of each channel. All the communication subsystem assemblies are redundant.

The DSCS II satellites are launched in pairs. The first launch was in November 1971. At first, both satellites operated properly, but major problems occurred in each in the year following launch, and they ceased to operate in September 1972 and June 1973. Analyses of these problems provided the basis for design modifications for the following satellites. The next pair was launched in December 1973. One failed in 1976; the other is experimental. The third pair was launched in May 1975 but, because of a launch vehicle failure, they did not achieve a useful orbit.

Late in 1974, a set of six replenishment satellites was ordered by the United States Government. Later, a third group of four satellites was ordered. These four satellites have 40-W TWTs instead of 20-W TWTs, and all ten have one narrowbeam antenna defocused to provide area coverage (6-deg nominal beamwidth).

These ten satellites were launched to establish and maintain an orbital system of four active and two spare satellites. The first pair (Satellites 7 and 8) was launched in May 1977. The next pair was launched in March 1978 but was lost as the result of a launch vehicle malfunction. Satellites 11 and 12 were launched in December 1978, and Satellites 13 and 14 were launched in November 1979. Satellite 16 was launched in October 1982 with the first DSCS III, and Satellite 15 was launched in 1989 with the second DSCS III. Some of the older satellites have been moved above the synchronous orbit.

* * * * *

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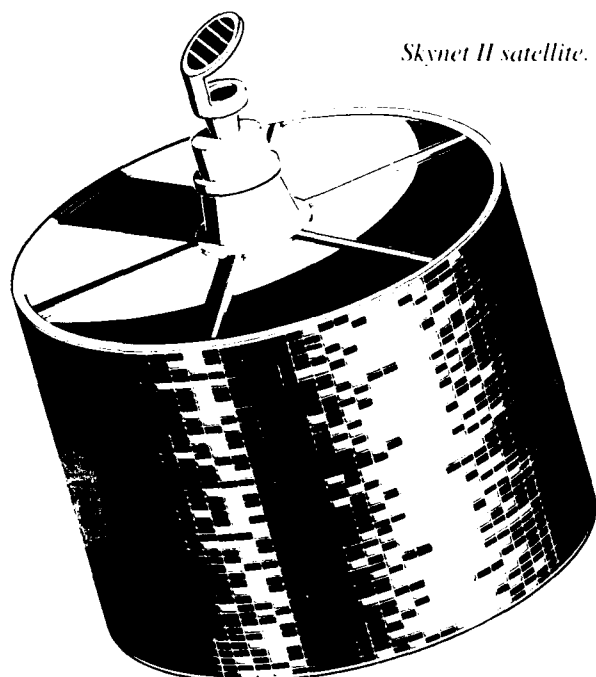
SKYNET II

Skynet is the name of the British military communication satellite system. The first-generation satellites (Skynet I) were launched in 1969 and 1970. One of these satellites operated successfully for several years, but the other was lost as the result of an apogee motor failure. The Skynet II satellites, with greater power and reliability, permitted the resumption of Skynet operations [1-7]. Although the British and United States requirements differed sufficiently to preclude a common military communication satellite system, the two systems were designed for some measure of interoperability.

The Skynet II design was similar to that of Skynet I, except that the Skynet II satellites were larger and heavier. The main body of the satellite was a spinning cylinder, with all the electronic equipment mounted on the inside. A despun earth coverage an-

tenna was mounted on one end of the satellite body. The larger satellite allowed a bigger solar array than that on Skynet I. Because of the additional power available, a 20-W TWT was used rather than the 3.5-W TWT on Skynet I. Skynet II also had more redundancy than Skynet I to increase the design life from three to five years.

The Skynet II repeater was a double-conversion type with 2-MHz and 20-MHz channels. There was no preamplifier before the downconverter. Each channel was amplified separately before being summed, limited, and amplified by one of the redundant TWTs. The amplifier gains were set so that the narrowband channel, which was used by small terminals, received 80% of the transmitter power. Other satellite and communication subsystem details were as follows:



Skynet II satellite.

Satellite

Cylinder, 75-in. dia., 53-in. height (82 in. overall)

517 lb in orbit, beginning of life

Solar cells and NiCd batteries, 200 W

Spin-stabilized

Solid rocket motor for apogee maneuver, hydrazine propulsion for on-orbit use

Configuration

One 2-MHz and one 20-MHz bandwidth double-conversion repeater

Transmitter

7257.3 to 7259.3 MHz and 7266.4 to 7286.4 MHz

Two TWTs (one on, one standby)

20-W TWT operated at approximately 18-W output

ERP: 26 dBW (2-MHz channel), 20 dBW (20-MHz channel), edge of earth

Receiver

7976 to 7978 MHz and 7985.1 to 8005.1 MHz

9-dB noise figure

Antenna

Mechanically despun horn, earth coverage, 18.7-dB peak gain (transmit), 19.9-dB peak gain (receive)

Design life

Five years

Orbit

Synchronous equatorial (inclination ≤ 3 deg)

Orbital history

A: launched 18 January 1974 (unsuccessful because of launch vehicle malfunction), decayed 25 January 1974

B: launched 22 November 1974, used until 1987, initial location about 49° E longitude, now drifting in Eastern Hemisphere

Delta 2313 launch vehicle

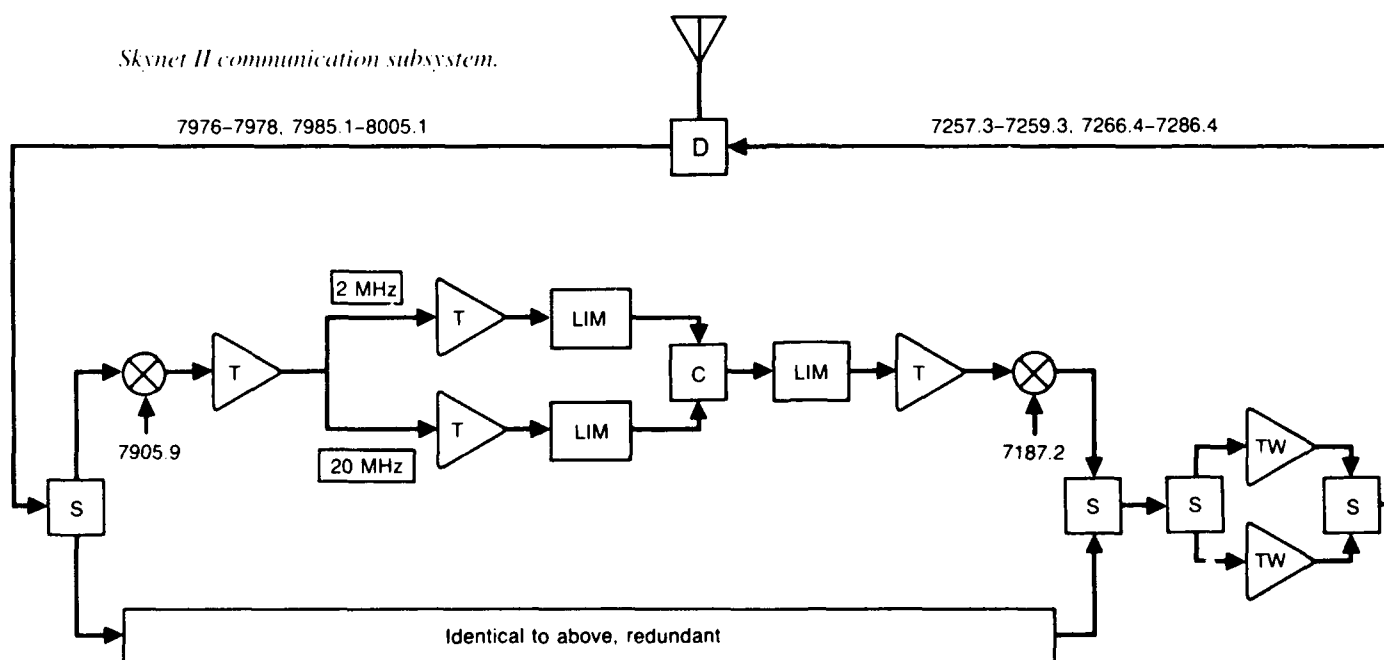
Management

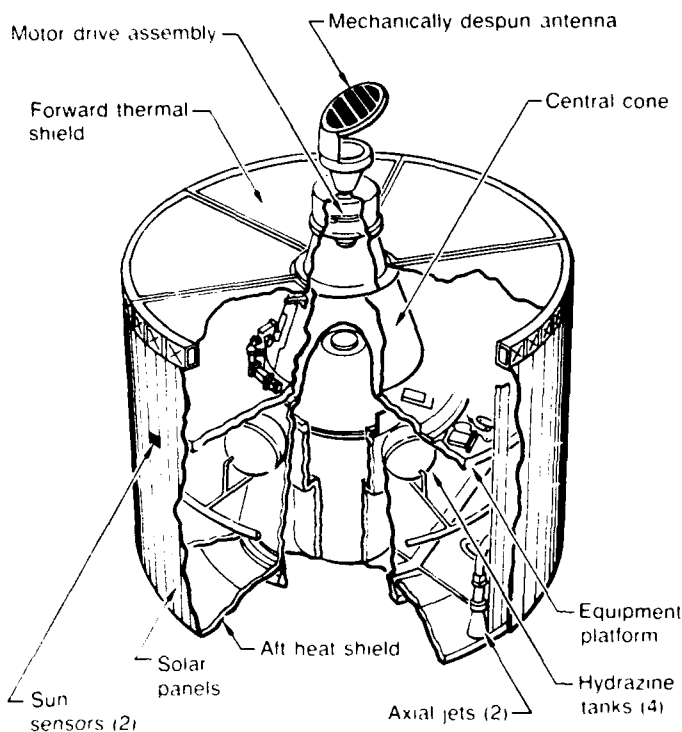
Developed by Marconi Space and Defence Systems Ltd. with Philco (later Ford Aerospace and Communications Corporation) as a principal subcontractor, for Air Force Space and Missile Systems Organization (now Air Force Space Systems Division), acting for the United Kingdom Ministry of Defence

Operated by United Kingdom Ministry of Defence

The Skynet II satellites were developed in Britain with United States assistance. Launch and orbital injection were handled by the United States, with Britain assuming control for on-orbit operations. The first Skynet II launch, in January 1974, was unsuccessful because of a launch vehicle malfunction. The remaining satellite was launched in November 1974. The command system

Skynet II communication subsystem.





Skynet II satellite details.

failed early in 1977 and, therefore, the satellite longitude could not be controlled after that time. Nevertheless, the satellite was in use until 1987.

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GAPFILLER/GAPSAT

Taesat and LES-6 were the first tactical communication satellites to be used by the Navy. However, they were both experimental satellites put into operational status and thus provided only a limited operational capability. The Navy started developing the Fleet Satellite Communications (FLTSATCOM) system in 1971 to provide a full operational capability with global deployment. Taesat failed in 1972 and LES-6 was deteriorating. Since the first FLTSATCOM launch was not expected until 1977, the Navy faced a gap in satellite availability. Therefore, in 1973 the Navy contracted for an interim satellite service to fill this gap. This service was called Gapfiller or Gapsat [1-8].

Each Gapfiller satellite had three UHF channels for the Navy, one wideband (500 kHz) and two narrowband (25 kHz). The wideband channel was chosen to have the same bandwidth and frequency as the LES-6 channel, and the narrowband channel bandwidth was set equal to the FLTSATCOM channel bandwidth. The minimal Navy commitment was to lease, for at least two years, the wideband channels of two satellites. The first satellite was launched in February 1976 and began operation the next month in the Atlantic area. Concurrently, LES-6 was turned off. The second satellite was launched in June 1976 and began operations in the Pacific area the same month. The wideband channels were divided into subchannels with FDMA operation with a capacity of five 2400-bps links, one 1200-bps link, and thirteen 75-bps links. One narrowband channel was also put into use by the Navy and the second was subleased to the Army. In October 1976, the third Gapfiller, which was primarily a spare for the other two, was launched to provide service in the Indian Ocean. At the same time, the leases on all three satellites were extended into 1979. Additional extensions continued Gapfiller service into 1986, on some channels. The British Navy started leasing some

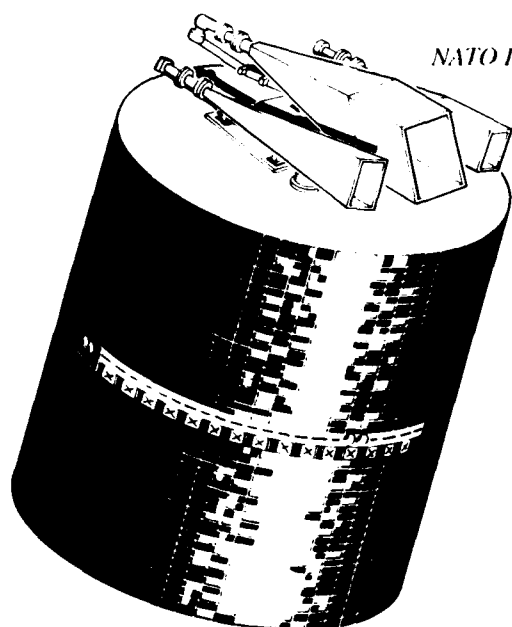
capacity on the Atlantic satellite early in 1981. Gapfiller use ended in 1989.

The Gapfiller service did not require the full capability of the satellites being used and, therefore, additional channels were used for communications between shore stations and commercial ships. This was called the Marisat system. These satellites, which are called either Gapfiller/Gapsat or Marisat satellites, depending on the context, are described later.

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NATO III satellite.

The NATO communication satellite program started in 1967. The first phase was the experimental use of the IDCSP satellites with two ground terminals. The second phase began in 1970 with the launch of the first NATO satellite. A second satellite was launched in 1971. These satellites were very similar to the Skynet I satellites. The NATO III satellites [1-10] are larger and have significantly greater capabilities than the earlier NATO satellites.

NATO III is a spin-stabilized satellite with a cylindrical body and a despun antenna platform on one end. All equipment is mounted within the body, and a three-channel rotary joint connects the communications subsystem with the antennas. The sat-

NATO III

ellite has a design life of seven years. The satellite details are as follows:

Satellite

Cylinder, 86-in. dia., 88-in. (1-3)/84.5-in. (4) height; overall height 116 in. (1-3)/113.5 in. (4)

Approximately 740 lb (1-3)/790 lb (4) in orbit, beginning of life
Solar cells and NiCd batteries, 538 W maximum at beginning of life, 375 W minimum after seven years

Spin-stabilized, 90 rpm; antenna pointing accuracy ± 0.3 -deg azimuth, ± 0.4 -deg elevation

Solid rocket motor for apogee maneuver, hydrazine propulsion for on-orbit use

Configuration

17-, 50-, and 85-MHz bandwidth, single-conversion repeaters

Transmitter

Narrowbeam (European coverage):

7250 to 7267 MHz and 7352 to 7437 MHz

20-W (1-3)/40-W (4) output power

35-dBW EIRP over field of view (measured values have been >36.5 dBW); 38.3-dBW EIRP over field of view (4)

Widebeam (Atlantic coverage):

7277 to 7327 MHz

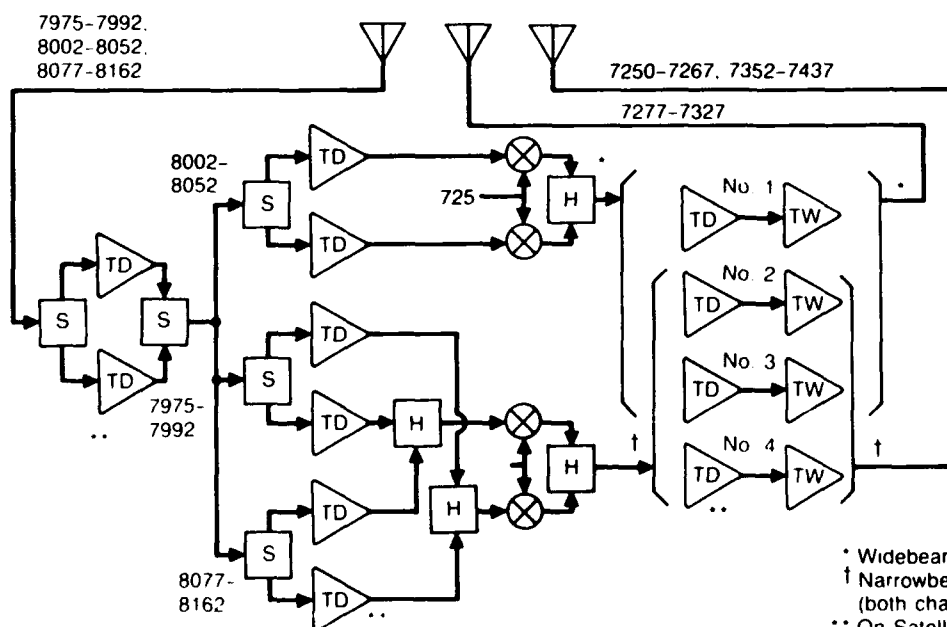
20-W (1-3)/40-W (4) output power

29-dBW ERP over field of view (measured values have been >31 dBW); 32.4 dBW over field of view (4)

Receiver

7975 to 7992 MHz, 8002 to 8052 MHz, and 8077 to 8162 MHz

Redundant tunnel diode preamplifiers (1-3)



NATO III communication subsystem.

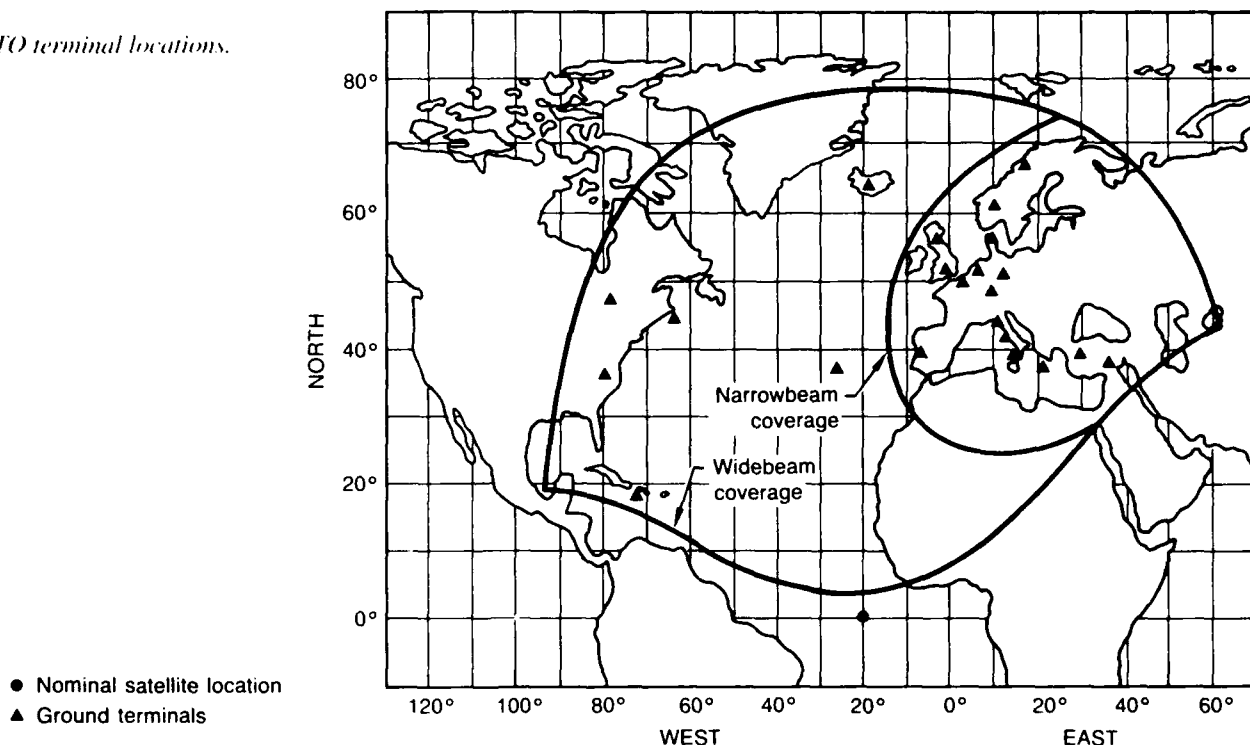
* Widebeam channel may use TWTA 1, 2, or 3

† Narrowbeam channel may use TWTA 2, 3, or 4

(both channels do not simultaneously use the same TWTA)

** On Satellite IIID all TDs are replaced by FETs

NATO terminal locations.



Redundant field effect transistors preamplifiers (4)
-14 dB/K G/T

Antenna

One widebeam (Atlantic coverage) receiving horn, 18.5-dB peak gain, 17.0-dB gain over $9.2^\circ \times 16^\circ$ field of view

One widebeam transmitting horn, 23.0-dB peak gain, 19.3-dB gain over $9.2^\circ \times 16^\circ$ field of view

One narrowbeam (European coverage) transmitting horn, 27.5-dB peak gain, 24.5-dB gain over $5.4^\circ \times 7.7^\circ$ field of view

All antennas circularly polarized

(The gains given are specification values; measurements indicate widebeam gains 1.3 to 2 dB higher and narrowbeam gains 0.5 to 0.8 dB higher.)

Design life

Seven years

Orbit

Synchronous equatorial (inclination $\pm 3^\circ$), stationkeeping to $\pm 1/2^\circ$ E-W

Orbital history

IIIA: launched 22 April 1976, 125° W longitude, retired

IIIB: launched 27 January 1977, 60° W longitude, retired

IIIC: launched 18 November 1978, 18° W longitude, operational, spare after NATO IVA becomes operational

IIID: launched 14 November 1984, 21° W longitude, spare
Delta 2914 launch vehicle (1-3)

Delta 3914 launch vehicle (4)

Management

Developed by Ford Aerospace and Communications Corporation for Air Force Space Systems Division (formerly Air Force Space and Missile Systems Organization) acting for NATO

Operated by NATO, TT&C support by Air Force Satellite Control Facility

NATO III has three communication channels with 17-, 50-, and 85-MHz bandwidths, all of which can be used simultaneously. All channels are received through a horn antenna with a pattern covering the North Atlantic region, including the east coast of North America, all of western Europe, and the Mediterranean. This is called widebeam coverage. After a common tunnel diode preamplifier, the three channels are separated and each is amplified in a TDA. All these units are redundant. The 50-MHz channel is transmitted through the widebeam transmit path, whereas the other two channels are combined in the narrowbeam path. Four TDA driver TWTA chains are available. On Satellite IIID, FET preamplifiers and amplifiers replaced all the tunnel diode units. Each transmit path has a choice among three chains, although both paths cannot use a TWTA simultaneously. The widebeam transmit antenna is a horn with the same coverage as the receiving antenna. A larger horn provides narrowbeam coverage of western Europe only. The three antennas (one receive, two transmit) are each connected to separate channels in the rotary joint.

A qualification model and two flight model satellites were constructed. The first was launched in April 1976 and was put in operation after orbital testing was completed. NATO IIIB was launched in January 1977 as an orbiting spare. It was loaned to the United States to fill the east Pacific operating location of the DSCS system until at least four DSCS II satellites were available. This goal was realized as a result of the DSCS II launch in December 1978. DSCS traffic was removed from NATO IIIB in January 1979, and it was returned to its station over the Atlantic Ocean. NATO traffic was switched to NATO IIIB in December 1982, and NATO IIIA was used for ground terminal testing. The qualification model has been reworked into the third flight model and was launched in November 1978 and put into a dormant state, known as orbital storage. NATO IIIC was reactivated and became the primary NATO spacecraft in December 1986, and NATO IIIB became a test vehicle. In 1980, a follow-on contract was issued for a fourth satellite, which was launched in November 1984. The contract included an option for a fifth satellite, but

the option was not exercised. In 1991, NATO IVA will become the primary satellite, with NATO IIIC and IIID as spares.

The NATO III satellites are part of the NATO satellite communications system. This system has a main control center and an alternative control center. Twenty-one fixed ground terminals, most with 42-ft antennas, and one transportable terminal communicate through the satellites. All transmissions are digital and share the satellite via FDMA. The satellite communication system is a part of the NATO Integrated Communications System, which also has various terrestrial communications links and switching and control nodes.

* * * * *

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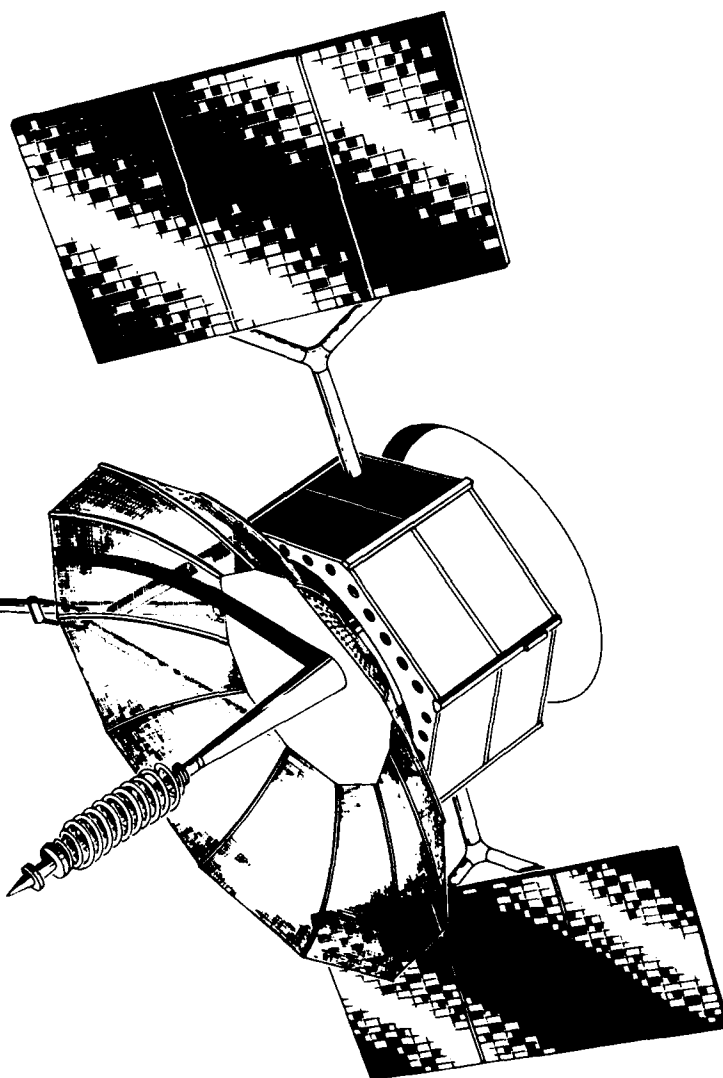
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FLTSATCOM AND AFSATCOM

Tacsat and LES-5 and -6 were experimental satellites that demonstrated UHF (225- to 400-MHz band) links with mobile terminals. These satellites were used for numerous tests, and Tacsat and LES-6 provided a limited operational capacity for DoD. Tacsat ceased to operate at the end of 1972, and LES-6 operated into 1976, although its performance had degraded considerably since it was launched. The Gapfiller satellites provided a limited operational capability beginning in 1976. This capability was significantly improved as the FLTSATCOM satellites were deployed. The Gapfiller/FLTSATCOM system is DoD's first operational, rather than experimental, system for tactical users [1-24].

FLTSATCOM serves Navy surface ships, submarines, aircraft, and shore stations. Air Force Satellite Communications (AFSATCOM) serves Air Force strategic aircraft, airborne command posts, and ground terminals. The two systems share a set of four FLTSATCOM satellites in synchronous equatorial orbits. The

FLTSATCOM satellite.



Air Force also has communications equipment packages on several satellites in high inclination orbits to provide coverage of the north polar region, which is not visible from the equatorial satellites.

The FLTSATCOM satellites have a hexagonal body composed of two modules. The last two satellites have a third module for the extremely high frequency (EHF) communications package

described later in this section. This third module has the same hexagonal shape as the other two but only half the height; it is mounted behind the other two (i.e., the side of the satellite facing away from the earth). The spacecraft module contains the attitude control, power, and TT&C subsystems as well as the apogee motor. The two solar arrays are mounted on booms attached to this module. The satellite is three-axis-stabilized by means of redundant reaction wheels and hydrazine thrusters. This type of stabilization allows the antennas to face the earth continuously while being directly attached to the satellite body. The solar array booms are always parallel to the earth's axis; motors keep the arrays oriented toward the sun.

The other module of the satellite contains the communication subsystem. The antennas are mounted on the earth-viewing side of this module. The largest antenna is for UHF transmissions and is a 16-ft diameter paraboloid with a solid center section. The outer part of the surface is a mesh that is attached to twelve ribs. The mesh is deployed, along with the solar arrays, after the satellite is injected into synchronous orbit. The separate UHF receiving antenna is a single helix about 1 ft diameter \times 11 ft long, deployed to the side of the large paraboloid. The third antenna is a horn that is used for reception of the X-band (super high frequency or SHF) fleet broadcast uplink and transmission of an X-band beacon. The satellite details are as follows:

Satellite

Hexagon, 7.5 ft across, 4 ft (5 ft, Satellites 7 and 8) in height, with two deployed solar arrays (each approximately 9 \times 13 ft) and a 16-ft deployed antenna, overall span 43.4 ft, overall height 21 ft (22 ft, 7 and 8)

2250 lb (2700 lb, 7 and 8) in orbit, beginning of life

Sun-tracking solar array and NiCd batteries, approximately 1570 W (approximately 2200 W, 7 and 8) at beginning of life, approximately 1210 W (approximately 1560 W, 7 and 8) minimum after five years

Three-axis-stabilized using momentum wheels, accuracy better than ± 0.2 deg (pitch and roll) 99% and ± 1 deg (yaw) 3σ

Solid rocket motor for apogee maneuver, hydrazine propulsion for on-orbit use

Configuration

Channel 1: X-band uplink to UHF downlink, 25-kHz bandwidth

Channels 2 to 9: 25-kHz bandwidth (UHF)

Channels 11 to 22: 5-kHz bandwidth (UHF)

Channel 23: 500-kHz bandwidth (UHF)

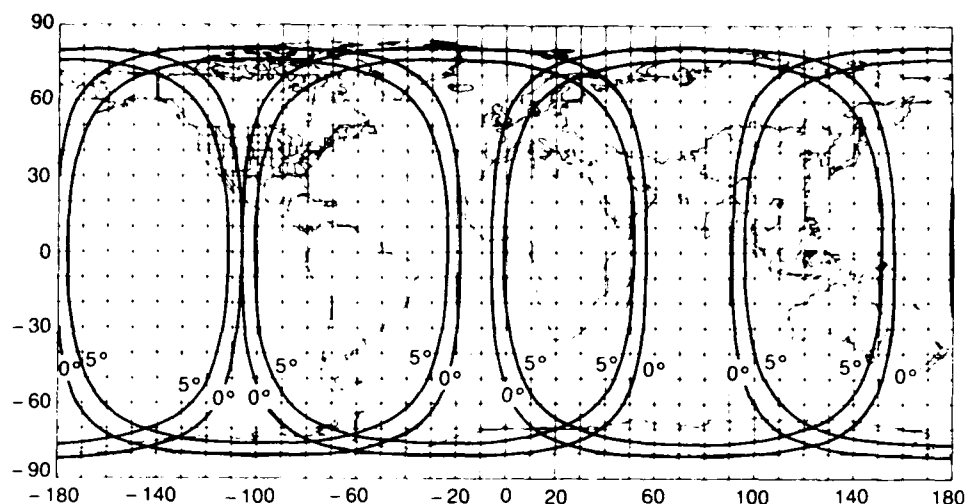
EHF (7 and 8): 32-channel processing

Transmitter

240- to 270-MHz band

Twelve transistor power amplifiers, 25- to 43-W output per amplifier, each with full redundancy

ERP per channel (edge of earth): 26 dBW, Channels 1 to 3, 5, 7 to 10; 28 dBW, Channels 4, 6; 16.5 dBW, Channels 11 to 22; 27 dBW, Channel 23



FLTSATCOM communication coverage.

In-orbit ERP exceeds these specifications by about 2 dB

EHF (7 and 8): 20-GHz band, 20-W TWT plus spare, on-board processor switches output between spot and earth coverage beam

Receiver

290 to 320 MHz, 8 GHz, and 44 GHz (7 and 8)

Antenna

16-ft deployable UHF parabola, earth coverage, circularly polarized

Deployable UHF helix, 1-ft dia., 12 ft long, earth coverage, circularly polarized

X-band horn, earth coverage, circularly polarized

EHF (7 and 8): steerable 8 in. dia. reflector providing a 5-deg spot beam with separate 20- and 44-GHz feeds, two earth coverage horns (one each for 20 and 44 GHz)

Design life

Five years (3.1 years MMD predicted before first launch; seven years MMD expected from experience through 1986)

Orbit

Synchronous equatorial (inclination < 3 deg; up to 5 deg accepted beyond five years), stationkeeping to ± 1 E-W

Orbital history

1: launched 9 February 1978, in use, 177 W longitude

2: launched 4 May 1979, in use, 73 E longitude

3: launched 17 January 1980, in use, 22 W longitude

4: launched 30 October 1980, in use, 172 E longitude

5: launched 6 August 1981, damaged at launch, out of service, moved above synchronous orbit

6: destroyed during launch 26 March 1987

7: launched 4 December 1986, in use, 100 W longitude

8: launched 25 September 1989, in use, 23 W longitude

Atlas-Centaur launch vehicle

Management

Developed by TRW Systems Group for Air Force Space Systems Division (formerly Air Force Space and Missile Systems Organization)

Operated by Naval Telecommunications Command until mid-1980s, Naval Space Command since, TT&C support by Air Force Satellite Control Facility

The satellite has four types of communication channels. The Navy uses one fleet broadcast channel and nine 25-kHz bandwidth fleet relay channels. The Air Force uses twelve narrowband (5 kHz each) channels and one wideband (500 kHz) channel. All links, except the fleet broadcast uplink, are in the 240- to 400-MHz band with the downlinks at the lower part of the band. The fleet broadcast uplink frequency is about 8 GHz. Either processing or nonprocessing receivers may be used with the fleet broadcast and some Air Force narrowband uplinks. Use of the processing receivers provides some antijam capability. The satellite has twelve power amplifiers, one for each of the Navy channels, one for the Air Force narrowband channels, and one for the Air Force wideband channel. A UHF command channel is provided on FLTSATCOM for operational control of the Air Force narrowband package and limited redundancy switching of the fleet broadcast channel.

The fleet broadcast channel has an information rate of 1200 bps composed of fifteen teletype and one synchronization channel

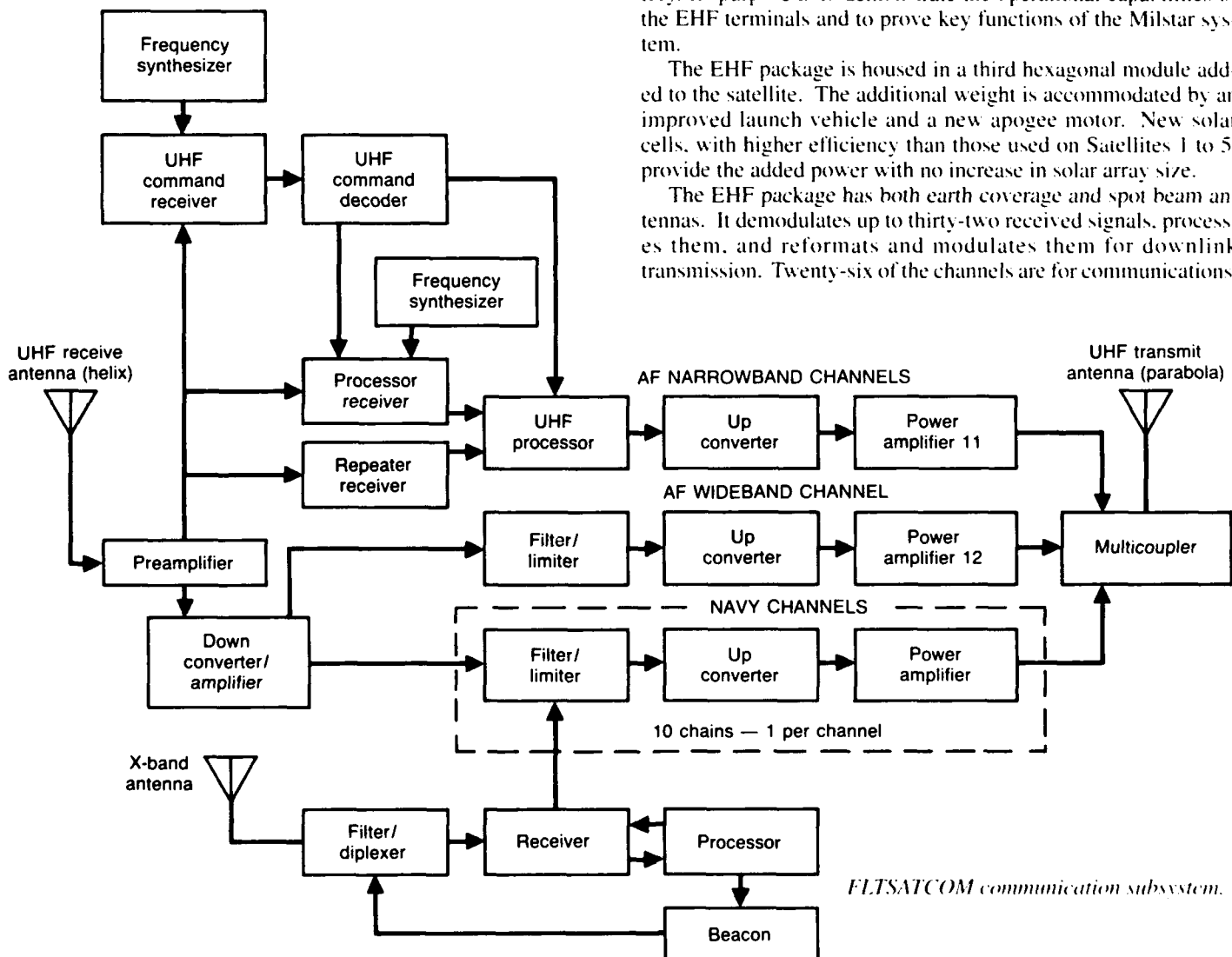
at 75 bps each. The initial use of each fleet relay channel is a single 1200- or 2400-bps link. To make better use of the channel capacity, the Navy is changing to TDMA transmissions with preassignment, followed by automated demand assignment. Tests of TDMA with demand assignment were conducted in 1978. By the second half of the 1980s, operational equipment was in use on many ships; extension to aircraft and submarines was planned to be done by the mid-1990s. The TDMA format uses burst rates between 9.6 and 32.0 kbps. Each narrowband Air Force channel is used for a single 75-bps link. The wideband channel is used for multiple FDMA links at 75 bps or a single higher rate link.

AFSATCOM does not have its own satellites for the polar coverage orbits. Rather, UHF communications packages are placed on other DoD satellites. These packages have capabilities similar to those of the twelve narrowband Air Force channels on the FLTSATCOM satellites. In addition, AFSATCOM uses a single-channel transponder with antijam improvements on DSCS III satellites.

Satellites 7 and 8 have an EHF communications package with a 44-GHz uplink and 20-GHz downlink. This package is called the FEP (FLTSATCOM EHF Package). It uses a Milstar-compatible signal structure. The FEP was developed by Lincoln Laboratory. Its purpose is to demonstrate the operational capabilities of the EHF terminals and to prove key functions of the Milstar system.

The EHF package is housed in a third hexagonal module added to the satellite. The additional weight is accommodated by an improved launch vehicle and a new apogee motor. New solar cells, with higher efficiency than those used on Satellites 1 to 5, provide the added power with no increase in solar array size.

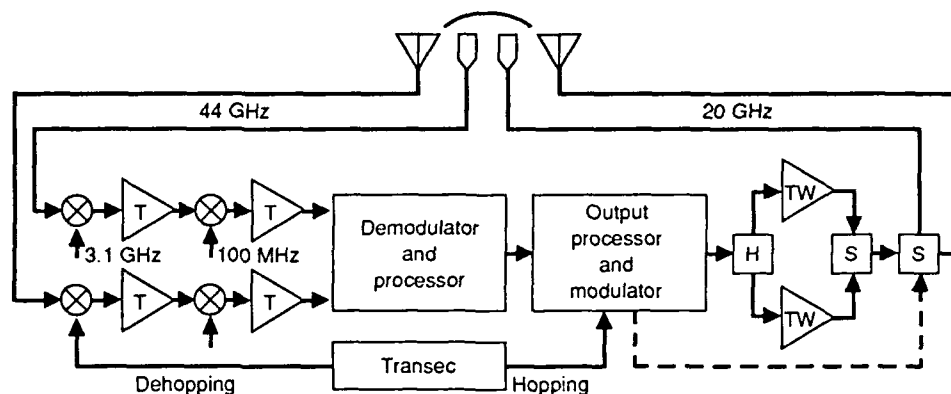
The EHF package has both earth coverage and spot beam antennas. It demodulates up to thirty-two received signals, processes them, and reformats and modulates them for downlink transmission. Twenty-six of the channels are for communications.



FLTSATCOM communication subsystem.

The FLTSATCOM program started with five satellites. Congress reduced the program to three, but the other two were restored later. The first satellite was launched in February 1978, and the fifth was launched in August 1981. The first four satellites formed a constellation with global coverage. Each has operated satisfactorily since it was put in orbit and has provided service for more than twice its design life. The fifth satellite was damaged during ascent and is not useable.

In 1982, three satellites were added to the program. Only the last two have the FEP. Satellite 7, with FEP, was launched before Satellite 6 to provide the earliest possible EHF capability in orbit. Satellite 6 was destroyed when lightning struck the launch vehicle during ascent. Both Satellites 7 and 8 are operating as expected. The FLTSATCOMs will be replaced by the UHF Follow-On satellites.

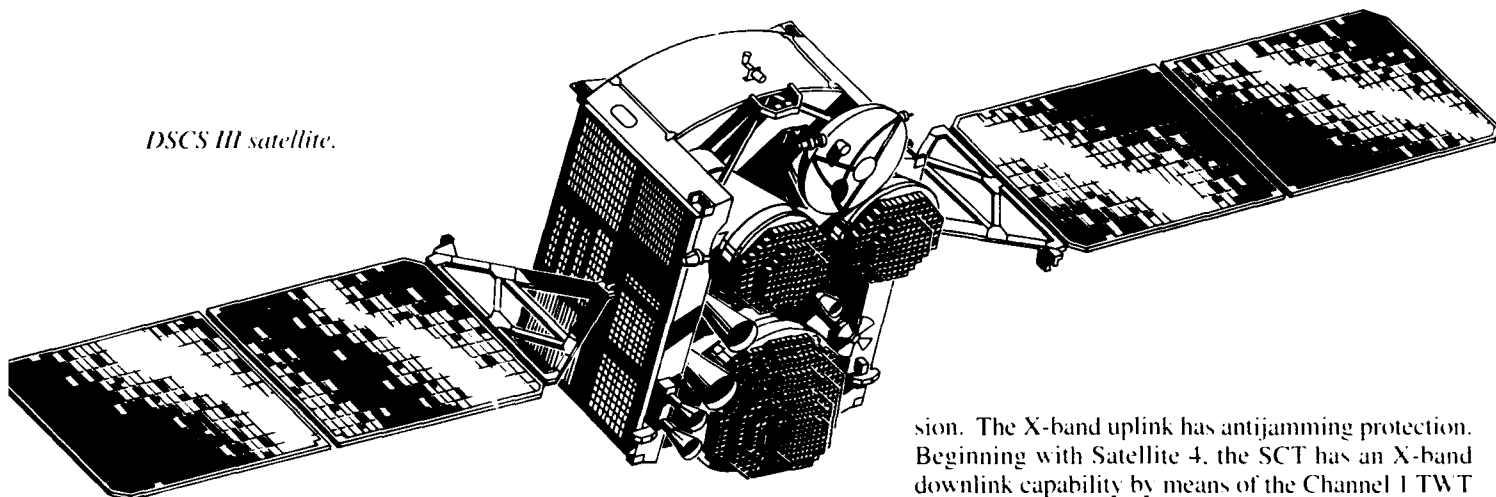


FLTSATCOM EHF communication subsystem.

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DSCS III

DSCS III satellite.



The Defense Satellite Communications System (DSCS) satellite constellation has five operating locations. The DSCS was originally planned for long-distance communications between major military locations. However, as the system has evolved, there has been an increase in both the number and variety of terminals. In the 1990s, a majority of the DSCS terminals are small, transportable, or shipboard types. The DSCS III satellites [1-8] have been developed to operate in this diverse environment.

The primary DSCS III communication subsystem has eight antennas that can be connected in various ways to the six transponders. Each transponder has its own limiter, mixer, and transmitter and, thus, can be configured to serve a specific type of user requirement. The configuration includes the choices of receiving antenna, transmitting antenna, and transponder gain level. Also, each transponder can be used with either FDMA or TDMA transmissions. The receivers have low noise field effect transistor preamplifiers. The midsections of the transponders are limiter amplifiers with a gain commandable over a 24-dB range in addition to a 15-dB commandable attenuator. These amplifiers can be operated in either a linear, quasilinear, or limiting mode. The transmitter drivers are field effect transistor amplifiers, and the power amplifiers are either 40-W or 10-W TWTs or 10-W solid state amplifiers.

There are two earth coverage and one multibeam receiving antennas. Four of the six transponders can be connected to the multibeam antenna (MBA). This antenna can form a beam of variable size, shape, and location by means of a beam-forming network that controls the relative amplitudes and phases of each of the sixty-one individual beams. This antenna can also form nulls in selected directions in order to counter jammers. Two transmitters are always connected to earth coverage antennas, but the other four may all be connected to one of two 19-beam transmit MBAs. These antennas have the same capabilities as the receive MBA (except nulling), although their resolution is lower. Three of the channels can also be switched to a gimbaled dish antenna (GDA) that generates a single beam with high effective isotropic radiated power (EIRP).

The secondary communication subsystem on DSCS III is the AFSATCOM single channel transponder (SCT). The SCT has its own UHF transmitting and receiving antennas but can be connected to the X-band earth coverage or MBA receiving antennas. The SCT demodulates the received uplink and remodulates it for transmission and can also store messages for repeated transmis-

sion. The X-band uplink has antijamming protection. Beginning with Satellite 4, the SCT has an X-band downlink capability by means of the Channel 1 TWT and MBA.

The DSCS III satellite is three-axis-stabilized. All antennas except the GDA are mounted on the earth viewing face of the body and do not require deployment. The sun-tracking solar arrays are deployed in orbit from the north and south faces of the satellite body. All support subsystems except the solar arrays are contained within the body. The early DSCS III satellites had no apogee motor; they were delivered to synchronous orbit by the launch vehicle. After a change of launch vehicle, a bipropellant apogee motor stage was designed and incorporated into the satellite. This stage had to be retrofitted into several already built satellites, and for this reason the Block B launch order differs significantly from the production sequence. The TT&C subsystem has an S-band section for use with the Satellite Control Network (SCN), which is common to nearly all DoD satellites, plus an X-band section for use with the communications terminals. This provides redundant command paths into the satellite and allows the communications users direct control of the antennas and transponders. The satellite and communications subsystem details are as follows:

Satellite

Rectangular body, approximately $6 \times 6 \times 10$ ft, overall span of deployed solar arrays 38 ft

2475 lb in orbit, beginning of life (2580 lb for Satellite 4 and up)

Sun-tracking solar arrays and NiCd batteries, 1240 W beginning of life, 930 W after ten years

Three-axis-stabilized using reaction wheels, 0.08-deg accuracy in pitch and roll, 0.8 deg in yaw, 0.2-deg antenna pointing accuracy

Liquid propellant apogee maneuver propulsion (launches beginning in 1989), hydrazine propulsion for on-orbit use

Configuration

Satellites 1 through 7 provide channel bandwidths of 60, 60, 85, 60, 60, and 50 MHz for Channels 1 through 6, respectively, with the frequencies shown on the block diagram; Satellites 8 through 14 provide a total of 30 MHz more bandwidth allocated as follows: 50, 75, 85, 85, 60, and 50 MHz, respectively, for Channels 1 through 6

Transmitter

Channels 1 and 2: 40-W TWT and spare for each; EIRP/channel 40 dBW (MBA, narrow coverage), 29 dBW (MBA, earth coverage), or 44 dBW (GDA)

Orbital history

A1: launched 30 October 1982 with DSCS II-16, operational, 130°W longitude

A2: launched in 1989 with DSCS II-15, operational

A3: in storage

B4, B5: launched together in 1985, operational

B6-B13: in storage, launches planned in 1992 to 1996

B14: launch scheduled early 1992

Titan 34D/IUS launch vehicle (A1)

Titan 34D/Transtage (A2)

Atlas II launch vehicle (B6 to B14)

Management

Developed by GE for Air Force Space Systems Division

Operated by Defense Information Systems Agency (formerly Defense Communications Agency). TT&C support by Air Force Satellite Control Network and Satellite Configuration Control Elements (SCCE)

DSCS III design studies and breadboards of certain components, particularly the MBAs, were carried out in 1976. Final development started in 1977 on a qualification model and two flight models (these three satellites are called Block A satellites), the first of which was launched in October 1982 with a DSCS II satellite and is operational. Three others have been launched and more launches are scheduled. The launches will establish and maintain an orbital constellation of at least five active and two spare satellites.

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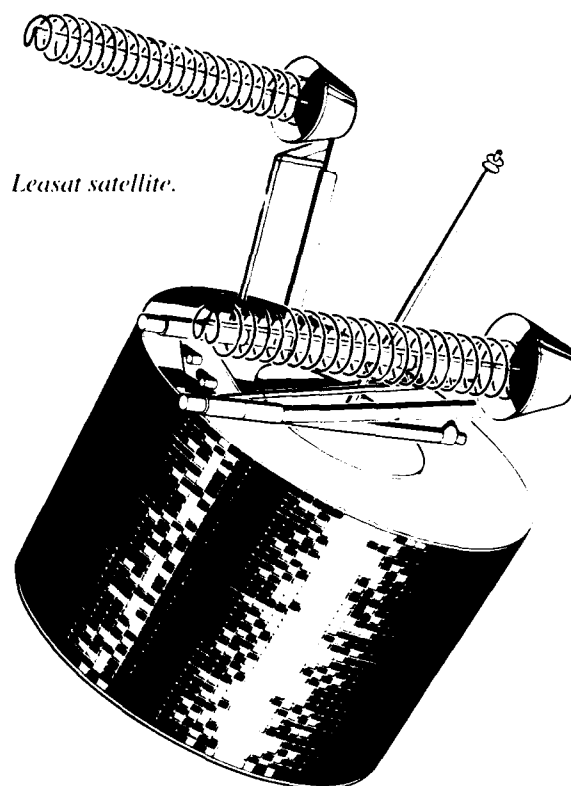
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LEASAT

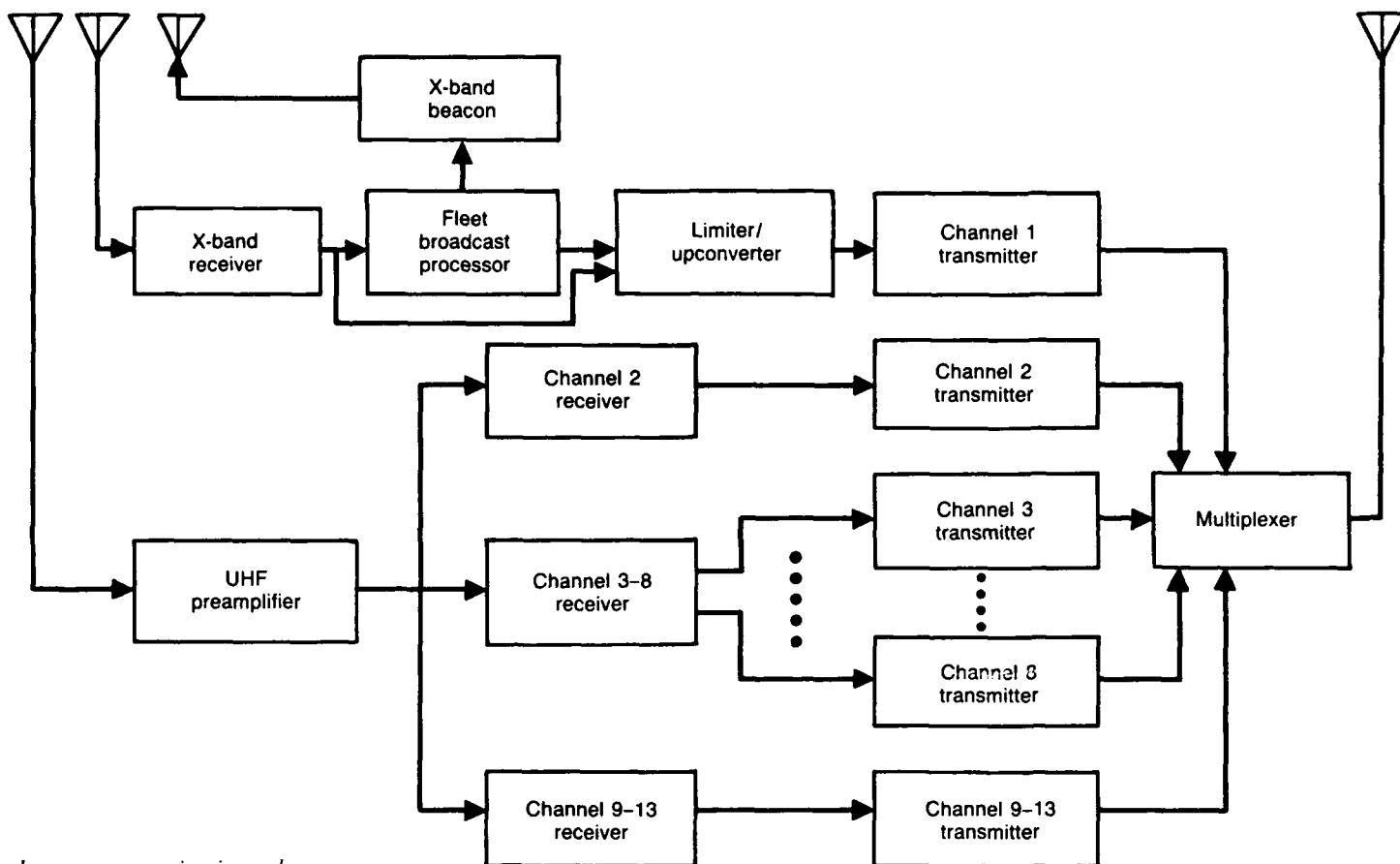
In the 1976 and 1977 Congressional reviews of the DoD budget for communication satellite systems, Congress directed DoD to increase its use of leased commercial facilities. This direction was specifically applied to the tactical satellite system that would follow FLTSATCOM. In the second half of 1977, the Defense Communications Agency (DCA), the Navy, and the Air Force developed technical, programmatic, and fiscal details for system alternatives that would satisfy DoD requirements within the Congressional guidelines. The result of this study is the Leasat program [1-12]. Leasat serves the Navy primarily, plus Air Force and ground forces mobile users. The FLTSATCOM terminal assets are used with Leasat.

Leasat has four types of communication channels with characteristics very similar to the FLTSATCOM channels. Channel 1 is for fleet broadcast use and has an X-band uplink with spread spectrum antijamming protection. The spectrum spreading is removed by a satellite processor, and the data are transmitted on a UHF downlink. Channels 2 through 13 have UHF uplinks and downlinks with no satellite processing. Channel 2 has a 500-kHz bandwidth. Channels 3 to 8 have 25-kHz bandwidths, and Channels 9 to 13 have 5-kHz bandwidths. Channels 9 to 13 share a power amplifier; Channels 1 through 8 each have a separate amplifier.

The Leasat satellite has a dual-spin configuration with a cylindrical solar array about 14 ft in diameter and 9 ft in height. The design is basically the same as the Syncom 4 design developed by Hughes in an effort to optimally match a satellite to the Space



Leasat satellite.



Leasat communication subsystem.

Shuttle launch system [2-4]. The central challenge in the Syncom 4 project was to find the combination of satellite geometry and upper stages that minimizes the mission cost for a given communications payload. This minimization is affected by three main facts:

- The payload bay diameter of the Shuttle is 15 ft, in contrast to the 8- and 10-ft fairing diameters of the launch vehicles for which all previous communication satellites were designed.
- The Shuttle launch cost is proportional to the fraction of the payload bay length used or the fraction of maximum payload weight capacity used, depending on which is greater.
- The basic Shuttle orbit altitude is 150 nmi. An upper stage or stages are required to get the satellite into synchronous equatorial orbit.

Leasat is a spinning satellite with a despun communications and antenna platform. For the purpose of allowing space for a cradle to hold the satellite in the Shuttle and to eject it properly, the satellite diameter was set at 14 ft. The length of the satellite body is set by the required size of the solar array. All required upper stage propulsion fits inside the satellite. In the bottom center of the satellite is a large solid propellant perigee motor that boosts the satellite into an elliptical transfer orbit after it is ejected from the Shuttle. In present satellites, this position is occupied by the apogee motor, if one is used. In the Syncom 4/Leasat design, the apogee boost function is provided by two liquid motors. These motors and the fuel tanks that feed them are mounted around the perigee motor. There is still sufficient volume within the satellite for the power supply electronics and batteries and the attitude

control subsystem. The communication subsystem is mounted on the despun platform at the forward end of the satellite body. The antennas are also mounted on this platform and are folded down against it during launch, then deployed when the satellite is stabilized at synchronous altitude.

Leasat has five antennas on the despun platform. Two are X-band, earth coverage horns, one for receiving the Channel 1 uplink and one for transmitting a beacon. An omnidirectional TT&C antenna is deployed in orbit. Two UHF helices are also deployed in orbit. Each provides earth coverage, one for transmission and one for reception. Additional satellite details are as follows:

Satellite

Cylindrical body, 13-ft, 10-in. dia., 9-ft height (approximately 21 ft overall)

2915 lb in orbit, beginning of life, 2760 lb after ten years

Solar array and NiCd batteries, 1500 W beginning of life, 1180 W minimum after five years

Spin-stabilized, 30 rpm, antenna pointing accuracy ± 0.5 deg

Solid rocket motor for perigee maneuver, bipropellant liquid propulsion for apogee maneuver, monopropellant hydrazine propulsion for on-orbit use

Configuration

Channel 1: X-band uplink, UHF downlink, 25-kHz bandwidth

Channel 2: UHF, 500-kHz bandwidth

Channels 3 to 8: UHF, 25-kHz bandwidth

Channels 9 to 13: UHF, 5-kHz bandwidth

Transmitter

244 to 270 MHz band, plus beacon at approximately 7300 MHz
Nine power amplifiers, one each for Channels 1 to 8, one for Channels 9 to 13

ERP per channel, minimum at edge of coverage: 26 dBW (1, 3 to 8), 28 dBW (2), 16.5 dBW (9 to 13)

Receiver

290- to 318-MHz band and approximately 8000 MHz

G/T (minimum at edge of coverage): -18 dB/K (UHF), -20 dB/K (X-band)

Antenna

Two UHF helices each about 1-ft dia. and 12.6 ft long (one transmit, one receive), 14-dB gain at edge of earth, and two X-band horns (one beacon, one receive), 17-dB gain at edge of earth; all earth coverage

Design life

Ten years

Orbit

Synchronous equatorial, inclination ≤ 3 deg, stationkeeping to ± 1 E-W

Orbital history

1: launched 8 November 1984 (deployed from Shuttle 10 November), in use, 16° W longitude

2: launched 30 August 1984 (deployed from Shuttle 31 August), in use, 177° W longitude

3: launched 12 April 1985 (deployed from Shuttle 12 April), failed to operate, repaired in low earth orbit August-September 1985, in use, 106° W longitude

4: launched 27 August 1985 (deployed from Shuttle 29 August), failed September 1985, moved above synchronous orbit

5: launched 9 January 1990 (deployed from Shuttle 10 January), in use, 72° E longitude

Management

Developed by Hughes Communication Services, Inc. (a subsidiary of Hughes Aircraft Company), and Hughes Aircraft Company for Naval Electronics Systems Command

Operated by Hughes Communication Services, Inc., and Naval Communications Command

The contract for Leasat development was awarded in September 1978 and is for five years of communication service to be provided at each of four orbital locations. The first launch was scheduled for 1982. However, delays in the Shuttle program delayed the launch dates and resulted in a two-year suspension of work on the satellites. Work resumed early in 1983, and the first two launches occurred in 1984. The delayed introduction of Leasat did not cause any problems, because the predecessor FLTSATCOM spacecraft operated much longer than expected.

The third Leasat was launched in April 1985, but the satellite failed to turn on. In the following days, the Shuttle crew carried out a rescue attempt, devised by NASA and contractor teams on earth, but it was unsuccessful. The fourth Leasat was launched in August 1985. The same Shuttle mission then rendezvoused with Leasat 3 and carried out a repair, which was successful, allowing

ground controllers to turn the satellite on and orient it. After a wait to ensure that the propellants were warm, Leasat 3 was placed into geosynchronous orbit in November 1985 and into operation the next month. Unfortunately, Leasat 4 failed shortly after arriving in geosynchronous orbit, and the wideband channel on Leasat 2 failed in October 1985. The fifth and last Leasat launch was in January 1990.

The Leasat contract includes an option for a two-year service extension beyond the basic five-year service period, and an option for the Navy to purchase the satellites after the two-year extension. The two-year option has been activated for the first three satellites. The first two options expire near the end of 1991; the Navy has announced their intention to purchase these satellites. The third option expires in late 1992. The five-year period for the fifth satellite expires in early 1995. Use of the remaining options on these satellites has not been decided. The Leasats, along with the FLTSATCOM satellites, will be replaced by the UHF Follow-On satellites.

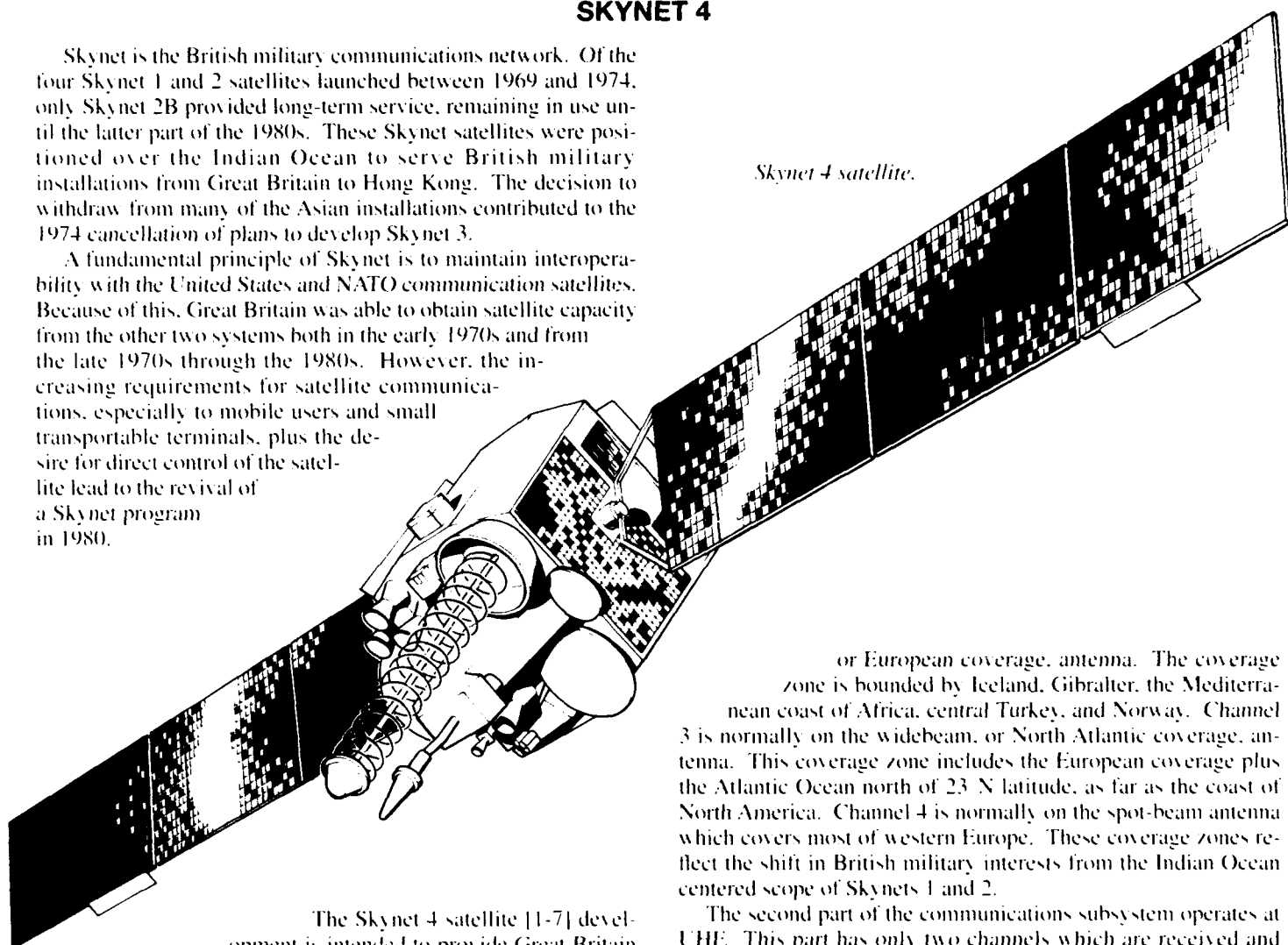
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SKYNET 4

Skynet is the British military communications network. Of the four Skynet 1 and 2 satellites launched between 1969 and 1974, only Skynet 2B provided long-term service, remaining in use until the latter part of the 1980s. These Skynet satellites were positioned over the Indian Ocean to serve British military installations from Great Britain to Hong Kong. The decision to withdraw from many of the Asian installations contributed to the 1974 cancellation of plans to develop Skynet 3.

A fundamental principle of Skynet is to maintain interoperability with the United States and NATO communication satellites. Because of this, Great Britain was able to obtain satellite capacity from the other two systems both in the early 1970s and from the late 1970s through the 1980s. However, the increasing requirements for satellite communications, especially to mobile users and small transportable terminals, plus the desire for direct control of the satellite lead to the revival of a Skynet program in 1980.



Skynet 4 satellite.

The Skynet 4 satellite [1-7] development is intended to provide Great Britain with military communication satellites through the 1990s. In 1980, two British contractors, each teamed with a United States contractor, conducted studies of the satellite concept. Early in 1981, these two teams submitted proposals for satellite development. After reviewing the proposals, the British Ministry of Defence directed the two companies to submit a joint, all-British proposal. This was feasible, because one company was strong in spacecraft and the other in communications payloads.

Development of Skynet 4 started late in 1982. The satellite is three-axis-stabilized with deployed solar arrays and is derived from the European ECS design. The UHF spiral antenna is deployed in orbit, but other antennas are fixed on the satellite body. The satellite has several survivability features including nuclear hardening, on-board signal processing, spread spectrum on some links, and secure telemetry and command links via both the separate telemetry and command links and the communications links.

The communications subsystem operates in three frequency bands. The primary band is SHF (7/8 GHz) with four channels handled by three amplifiers. The channels are normally received through an earth coverage antenna, but the spot-beam antenna can be used instead. The four channels are normally transmitted through four separate antenna beams, although each of the three not normally on earth coverage can be switched to it. Channel 1 is on earth coverage; Channel 2 is normally on the narrowbeam,

or European coverage, antenna. The coverage zone is bounded by Iceland, Gibraltar, the Mediterranean coast of Africa, central Turkey, and Norway. Channel 3 is normally on the widebeam, or North Atlantic coverage, antenna. This coverage zone includes the European coverage plus the Atlantic Ocean north of 23° N latitude, as far as the coast of North America. Channel 4 is normally on the spot-beam antenna which covers most of western Europe. These coverage zones reflect the shift in British military interests from the Indian Ocean centered scope of Skynets 1 and 2.

The second part of the communications subsystem operates at UHF. This part has only two channels which are received and transmitted through an earth coverage beam. These channels are primarily for submarine communications, although they can be used by land mobile units and aircraft. The third part of the communications subsystem is an experimental EHF (44 GHz) uplink. The purpose of this equipment is to test increased jam resistance not obtainable with UHF and SHF. Signals received on this uplink are processed and routed, through the considerable on-board switching arrangements, to the SHF downlink.

Additional description of the satellite and the communication subsystem is available below.

Satellite

Rectangular body, approximately 5 × 6 × 6 ft, approximately 53-ft span across solar arrays

1600-1700 lb in orbit, beginning of life

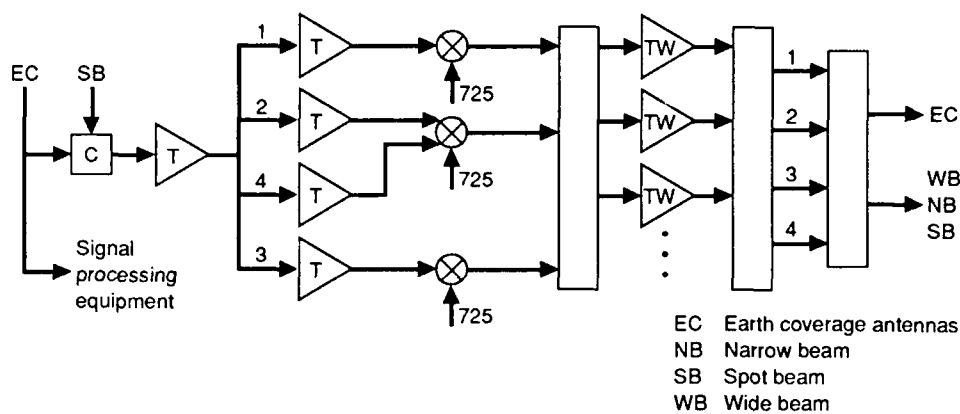
Sun-tracking solar arrays and batteries, approximately 1600 W at beginning of life, 1200 W after seven years

Three-axis-stabilized using momentum wheels, pointing accuracy 0.07 deg in pitch and roll, 0.35 deg in yaw

Solid rocket motor for apogee maneuver, hydrazine propulsion for on-orbit use

Configuration

UHF: two 25-kHz bandwidth channels with on-board signal processing



Skynet 4 SHF communication subsystem.

SHF: four channels with bandwidths of 135, 85, 60, and 60 MHz, with on-board processing

EHF: one experimental uplink receiver

Transmitter

UHF: in 250- to 260-MHz band

40-W solid state amplifiers, two active plus spares

26-dBW ERP per channel at edge of earth

SHF: 7250 to 7385, 7420 to 7505, 7530 to 7590, 7615 to 7675 MHz

40-W TWTAs, three active (one each for Channels 1 and 3, one shared by Channels 2 and 4) plus spares

ERPs at edge of coverage 31 dBW (Channel 1, earth coverage), 34 dBW (Channel 2, European beam, also called narrow beam), 35 dBW (Channel 3, widebeam), 39 dBW (Channel 4, spot beam)

Receiver

UHF: in 305- to 315-MHz band

-18 dB/K G/T at edge of earth

SHF: 7975 to 8110, 8145 to 8230, 8255 to 8315, 8340 to 8400 MHz

FET preamplifiers

EHF: in 43- to 45-GHz band

Antenna

UHF: one spiral antenna approximately 1 ft in dia. \times 8 ft long, earth coverage

SHF: four horns (one receive, three transmit), earth coverage, approximately 17-dB gain two parabolic reflectors with multi-horn feeds to produce a widebeam with 21.7-dB gain, a narrow-beam with 24.7-dB gain, and a 3-deg spot beam with 29.5-dB gain, all gains at edge of coverage one special services parabolic reflector to produce nulls (for uplink all circularly polarized)

EHF: one horn antenna

Design life

Seven years

Orbit

Synchronous equatorial, $\pm 0.1^\circ$ E-W stationkeeping, no N-S stationkeeping, inclination $\leq 3^\circ$ over life by choice of initial orbit parameters

Orbital History

4A: launched 31 December 1989, 30 E longitude, operational

4B: launched 10 December 1988, 56°E longitude, spare

4C: launched 30 August 1990, 1°W longitude, operational

Titan III launch vehicle (4A), Ariane launch vehicle (4B, 4C)

Management

Developed by British Aerospace (spacecraft) and Marconi Space Systems (payload) for United Kingdom Ministry of Defence

Operated by Ministry of Defence

The SHF part of the satellite is used by many terminals on land and on ships. About forty ships already have communications equipment. Many large aircraft, such as maritime patrol, cargo, and surveillance, are to have equipment installed by the mid-1990s. Ground forces use large transportable terminals with 21-ft diameter antennas, smaller transportable terminals with 6-ft antennas, and manpacks with antennas smaller than 2 ft. The largest of these terminals is capable of being set up by six men in three hours. The master satellite control station is at Oakhanger, England and has 42-ft antennas.

The initial Skynet 4 order was for two satellites, but a third was soon added to the contract. All three are in orbit and have passed their initial tests successfully. Two are in use and the third is a spare, positioned over the Indian Ocean at a longitude formerly used by the older Skynet satellites. It is possible that, by the mid-1990s, additional Skynet 4 satellites will be ordered, perhaps with enhanced capabilities.

* * * * *

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NATO IV

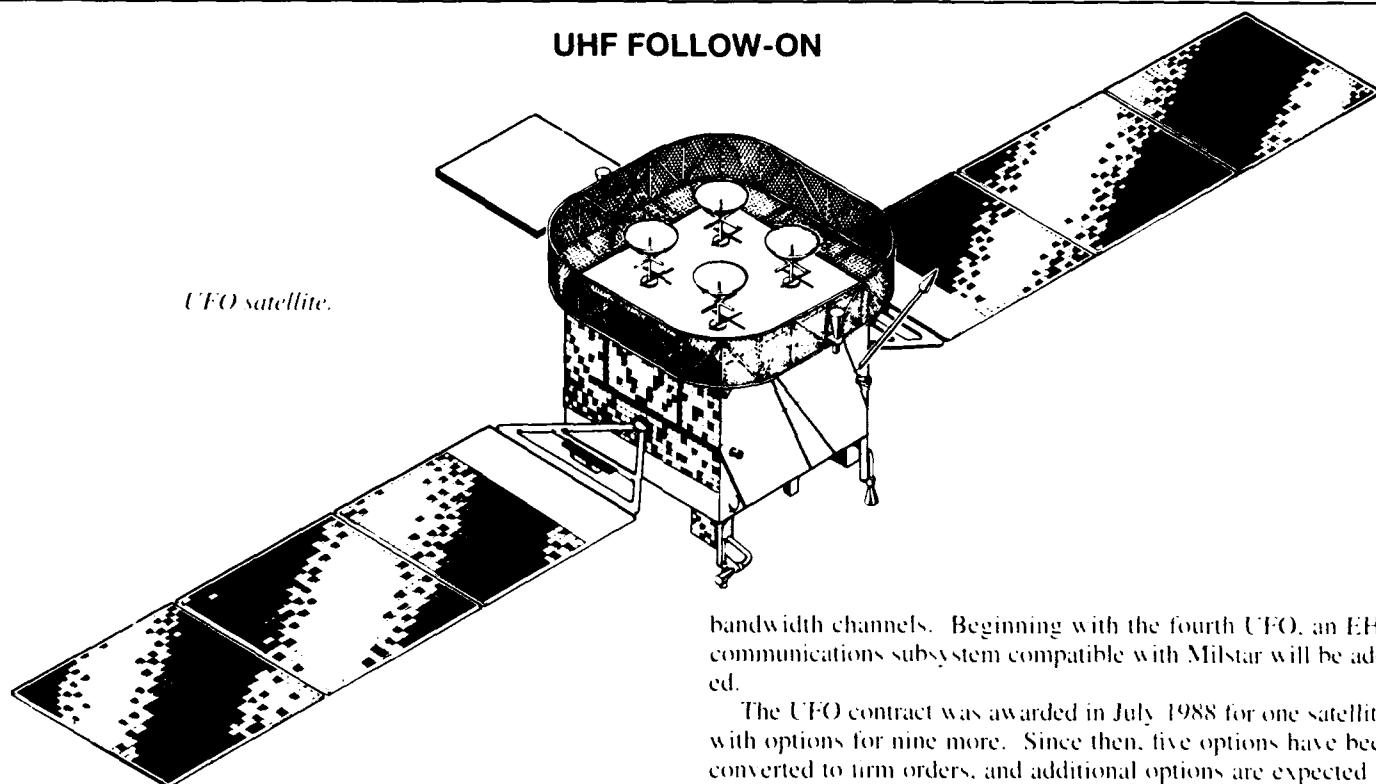
NATO IV satellites [1-3] will replace the NATO III satellites to continue communications support through the 1990s. In order to avoid the cost of a new satellite development, NATO decided to obtain copies of an existing design. The two candidates were the United States DSCS III and the British Skynet 4. The British satellite was chosen at the end of 1986, and work on two NATO IVs commenced in 1987.

NATO IV satellites are either identical to, or almost identical to, the Skynet 4 satellites. The satellite drawing in the Skynet 4 description is a good representation of NATO IV. The descriptive information tabulated there, except for launch dates, launch vehicles, and orbital locations, should be the same for NATO IV. The satellites are being procured by the British Ministry of Defence acting for NATO.

The first satellite was launched in January 1991 on a Delta launch vehicle. It will be the active NATO satellite. A second satellite will be a spare. It is scheduled for launch in December 1991, but the launch could be delayed a year if NATO IVA functions properly. The satellites will be used by the fixed site terminals that have been operating with NATO III satellites as well as by several dozen transportable terminals in construction.

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UHF FOLLOW-ON



UFO satellite.

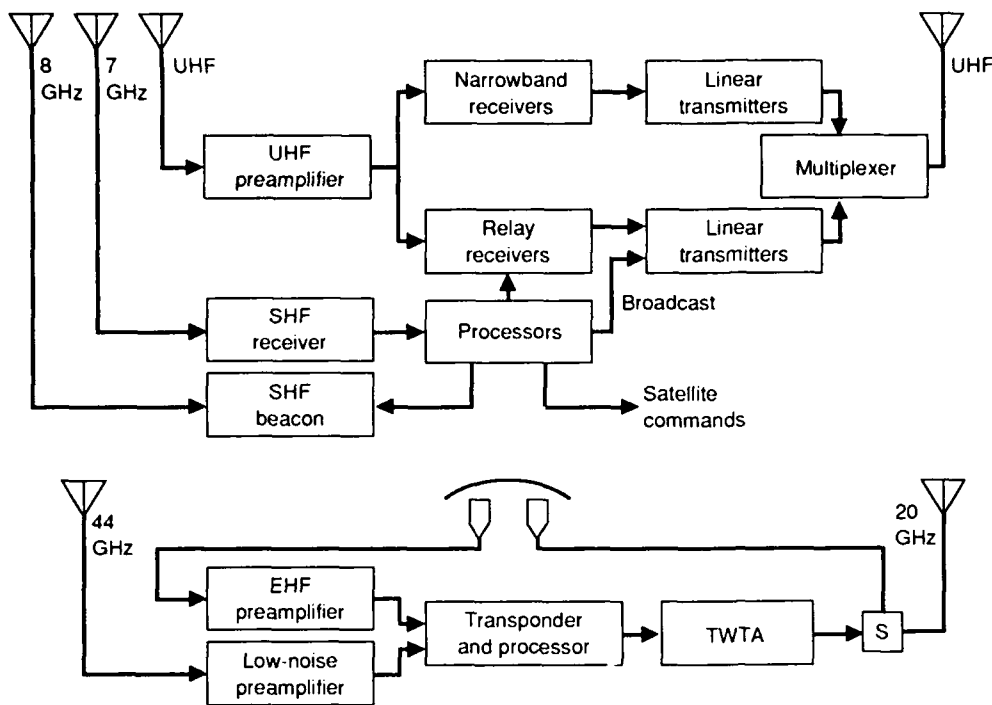
The UHF Follow-On, or UFO, program [1] will provide satellites to replace the Navy's FLTSATCOM and Leasat satellites. Navy requirements for UHF satellite capacity have grown considerably since the first FLTSATCOM was launched in 1978. At that time, four operational satellites plus one orbiting spare were planned. The current constellation is double that size and includes six FLTSATCOMs and four Leasats. These satellites are functioning properly, but half of them have exceeded their design lives, and all but one will be beyond design life by the end of 1995.

The Navy plans to replace the older satellites with a constellation of eight UFOs, plus one orbiting spare, between 1992 and 1996. The UFO satellites have more channels than the earlier satellites. However, they do not have their 500-kHz bandwidth channel, because it was found to be less useful than the narrower

bandwidth channels. Beginning with the fourth UFO, an EHF communications subsystem compatible with Milstar will be added.

The UFO contract was awarded in July 1988 for one satellite, with options for nine more. Since then, five options have been converted to firm orders, and additional options are expected to be exercised. The contract is a fixed price commercial type rather than the cost reimbursement types usually applied to military satellite developments. The justification is considerable experience with UHF satellites, which results in a low risk development. The contract also requires the manufacturer to obtain launch vehicles and deliver the satellites in orbit, unless the government chooses to provide Shuttle launches. The first three launches will definitely be arranged by the manufacturer.

The satellite body is nearly a cube. Solar arrays with three panels each deploy from the north and south faces when the satellite reaches orbit. A large UHF transmit antenna is fixed on the earth-viewing face of the satellite. A smaller UHF receive antenna is deployed in orbit; it is the square to the side of the transmit array in the satellite drawing. The satellite has a bipropellant propulsion subsystem which provides some of the perigee maneuver, all of the apogee maneuver, and the on-orbit control. The satellite design life of fourteen years is the longest to date, although many



UFO communication subsystem.

satellites in orbit have exceeded their design lives, and a few have operated over fourteen years. Other design information is as follows:

Satellite

Rectangular body 6 × 7 × 6 ft, span across solar arrays 60.7 ft, height 11 ft

2844 lb in orbit, beginning of life (Satellites 1 to 3)

Sun-tracking solar arrays and NiH₂ batteries, approximately 3000 W beginning of life, 2460 W minimum at end of life (Satellites 1 to 3)

Three-axis stabilization, antenna pointing accuracy 0.31 deg (rss of pitch and roll), 0.34 deg (yaw)

Liquid bipropellant propulsion for all mission phases

Configuration

One fleet broadcast channel, SHF uplink to UHF downlink, 25-kHz bandwidth, on-board processing

Seventeen relay channels, 25-kHz bandwidth, UHF

Twenty-one narrowband channels, 25-kHz bandwidth, UHF

Eleven processing channels, up to 2400 bps each, EHF (only on Satellites 4 and subsequent)

Transmitter

UHF: 243 to 270 MHz

Eleven solid state power amplifiers

ERP at edge of earth 29 dBW (broadcast and two relay channels), 27 dBW (other relay channels), 21 dBW (narrowband channels)

EHF: approximately 20 GHz

One active, one spare TWTAs

Receiver

UHF: 292 to 318 MHz

G/T -14.3 dB/K, edge of earth

SHF: approximately 8 GHz

G/T -17.2 dB/K, edge of earth

EHF: approximately 44 GHz

Antenna

UHF: transmit antenna 2 × 10.5 × 10.5 ft, array of four short backfire elements, 15.7-dB gain at 9.2 deg off axis

Receive antenna 2 in. × 5 × 5 ft, microstrip patch array, 12.5-dB gain at 9.2 deg off axis, circular polarization

SHF: two earth coverage horns: one for reception, one for transmission

EHF: two earth coverage horns: one for reception, one for transmission; one mechanically steerable parabolic antenna, 5-deg beamwidth

Design life

Fourteen years (12.6 years MMD)

Orbit

Synchronous equatorial, ±1° E-W stationkeeping, N-S stationkeeping only as needed to limit inclination to 5 deg

Longitudes 23°W, 100°W, 72°E, 172°E

Orbital History

1: launch scheduled mid 1992

2: launch planned 1994

3: launch planned 1994

4 to 6: launches planned 1994-1995

Atlas-Centaur launch vehicle

Atlas II-Centaur launch vehicle for Satellite 4 and subsequent

Management

Developed by Hughes Aircraft Company for Naval Space Command

Operated by Naval Space Command with support from Air Force Satellite Control Network

The satellite is hardened against nuclear radiation and can operate for thirty days without ground commands other than for payload reconfiguration and stationkeeping. The SHF fleet broadcast uplink, and the EHF links, will have spread spectrum signals for jamming resistance. The EHF signal structure is compatible with that of Milstar.

The EHF payload accommodates eleven FDMA uplinks, four through the earth coverage antenna and seven through the steerable antenna. Each uplink may be time shared by multiple users. The downlink is a time multiplexed combination of all eleven channels on a single carrier. Data rates between 75 and 1200 bps are possible in each channel, and any channel can be used for satellite command and telemetry. A switch will allow routing of signals from the EHF uplink to the UHF downlink.

Satellite control is exercised by the Navy Space Command. The primary satellite command and telemetry will be via the SHF

uplink and SHF downlink beacon. The S-band, Space-Ground Link Subsystem (SGLS) command and telemetry will be provided through the Air Force Satellite Control Network from launch through stabilization in synchronous orbit.

The first UFO is scheduled to be in orbit by July 1992. If all options are taken, there will probably be three more launches in 1994, three in 1995, and three in 1996. This would provide two satellites for each of the four operating locations, plus one spare. The tenth satellite will either be a ground spare or will be launched if another satellite is lost in a launch failure.

* * * * *

1. *Aviation Week & Space Technology* (21 March 1988), p. 46; (8 August 1988), p. 22; (21 August 1989), p. 22; (4 June 1990), p. 69.

MILSTAR

In the late 1970s and early 1980s, DoD was operating three types of communication satellite assets: DSCS, FLTSATCOM supplemented by the Gapfillers, and AFSATCOM. The FLTSATCOM satellites have been supplemented by the Leasats beginning in 1984. Following Leasat, a major system improvement called TacSatCom II was planned for the 1990s. A major improvement for the AFSATCOM system, called the Strategic Satellite System (SSS), was also planned to start in the mid-1980s.

Congressional opposition to these plans resulted in a consolidation of the two planned improvements into one new system called Milstar [1-7]. This system will provide service for mobile users in both strategic and tactical environments. The Milstar system and satellites are designed to be survivable, able to continue operations through all levels of conflict. The satellites are hardened to resist effects of nuclear radiation. They are connected via 60-GHz crosslinks to provide worldwide interconnectivity with a minimal dependence on ground relay nodes. Atmospheric attenuation is very high at the crosslink frequency, making the crosslink immune to ground-based interception and jamming. Satellite-ground links will be concentrated in the EHF band (44-GHz uplinks, 20-GHz downlinks) with spread spectrum waveforms designed to maximize resistance to jamming. Other links will use UHF for compatibility with the many UHF terminals already in use.

The Milstar concept was defined in 1980 and 1981. In 1982, work began on the FLTSATCOM EHF Packages (FEP) described earlier. Their purpose is to provide an early in-orbit, Milstar-compatible space asset for testing. In 1983, a satellite development contractor was selected, as were two payload development contractors. A critical design review was held in 1986, and satellite integration tests were conducted in 1990. The three military

services awarded multiple contracts since 1986 for terminal development and production. Various types of terminals, with antenna diameters between 6 in. and 8 ft. will be built for aircraft, ship, and land use. Throughout these years, Congress was debating the budget for Milstar and the scope of the program. At this time, the total number of satellites to be built and launched is uncertain but probably is less than the original plans for seven to ten satellites. The first launch will occur in the early 1990s.

* * * * *

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2. F. E. Bond, "Long Range MILSATCOM Architecture," *IEEE Military Communications Conference* (October 1982).
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5. J. Fawcette, "Milstar: Hotline in the Sky," *High Technology*, Vol. 3, No. 11 (November 1983).
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7. J. W. Rawles, "Milstar Soars Beyond Budget and Schedule Goals," *Defense Electronics*, Vol. 21, No. 2 (February 1989).

DEFENSE SATELLITE COMMUNICATIONS SYSTEM

* * * * *

The primary users of the DSCS [1-22] are the Worldwide Military Command and Control System, the ground mobile forces, Navy ships, wideband data relay, AUTOVON and AUTODIN, the White House Communications Agency, the Diplomatic Telecommunications System, and support to allied nations. In addition to the satellites, the DSCS includes a control segment and a variety of ground terminals.

Several types of ground terminals are in use. Some types are being developed to satisfy the increasing diversity of users in the DSCS. Airborne and shipborne terminals are the responsibility of the Air Force and Navy, respectively; the Army is responsible for all other terminals. By the end of the 1980s, most of the terminals were the truck- and trailer-mounted transportable types with 8-ft antennas, which are used by the ground mobile forces.

The table gives basic characteristics of several common land terminals. The capacity of each link varies from one to ninety-six voice circuits, or may be a combination of teletype and voice circuits or digital data at rates from several kilobits per second to greater than 10 Mbps. At present, both FDMA and spread spectrum multiple access (SSMA) are used, with some terminals having both types of equipment.

The configuration of the DSCS network is growing through the years and within any year may vary as necessary to support the users' responses to world events. Each of the five operational satellites and spare satellites has a primary and alternative network control station located at major nodes such as Ft. Detrick, Maryland. The five operational satellites correspond to five DSCS regions: east Atlantic, west Atlantic, Indian Ocean, east Pacific, and west Pacific. The change from a four- to five-region system occurred in the mid-1980s. There is considerable overlap between the areas served by adjacent satellites.

The DSCS control segment must allocate satellite capacity to best serve user requirements. Control segment computer algorithms provide an allocation process that makes use of the considerable flexibility of the DSCS III satellites. This flexibility includes the antenna patterns and connectivities and thus also involves variable EIRP and G/T. The control segment optimizes the network configuration for both FDMA and SSMA operations, responds to jammers, generates command sets to configure the satellite, and processes telemetry from the satellites.

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Table 1. Example DSCS Ground Terminals

PARAMETER	DESIGNATION			
	FSC-78	GSC-39	TSC-100A	TSC-94A
Type	Large, fixed site	Medium, fixed site	Transportable, ^a nodal	Transportable, ^a non-nodal
Antenna dia. (ft)	60	38	8 or 20	8
Maximum number of carriers (transmit/receive)	9/15	9/15	4/4	1/1
Transmitter power (W)	5000	5000	1000	500
EIRP (dBW)	94	89	70 or 77	67
G/T (dB/K)	39	34	18 or 26	18

^a Can be set up or taken down by four men in 30 minutes (8-ft antenna).

- AIAA 7th Communications Satellite Systems Conference* (April 1978).
12. B. E. Tyree, "An Overview of the Small SHF Satellite Ground Terminal Development Program," *RCA Engineer*, Vol. 22, No. 1 (June/July 1976).
 13. S. F. Rurak, "Ground Mobile Forces Tactical Satellite Terminals," *International Telemetry Conference Proceedings* (November 1980).
 14. A. L. Johnson and T. E. Joyner, "Small EHF/SHF Airborne Satcom Terminal," *International Telemetry Conference Proceedings* (November 1980).
 15. P. C. McLellan, "DSCS—An Evolving Operational System," *Signal*, Vol. 35, No. 6 (February 1981).
 16. W. P. McKee, "The Role of Satellite Communications in the Future DCS," Paper 6H.1, *International Conference on Communications: ICC '82* (June 1982).
 17. W. J. Hilsman and A. R. Garcia, "Defense Satellite Communication System: Another Milestone," *Signal*, Vol. 38, No. 1 (September 1983).
 18. J. E. Urner, "Multichannel SHF DAMA System," *1983 Military Communications Conference: Milcom '83* (October 1983).
 19. P. J. Bogert, "The Role of the DSCS Operational Support System in the Future DSCS Operations Control System Architecture," *1984 Military Communications Conference: Milcom '84* (October 1984).
 20. W. D. Powers and A. M. Hartigan, "The Defense Satellite Communications System," *Signal*, Vol. 39, No. 11 (July 1985).
 21. P. E. Bracher and R. P. Laskey, "Space and Terrestrial Systems in the Defense Communications System," *EASCON '88 Conference Record* (November 1988).
 22. J. R. Giroux, et al., "SHF MILSATCOM Technology Marches Ahead," *Microwave Systems News*, Vol. 20, No. 3 (March 1990).

SOVIET UNION SATELLITES

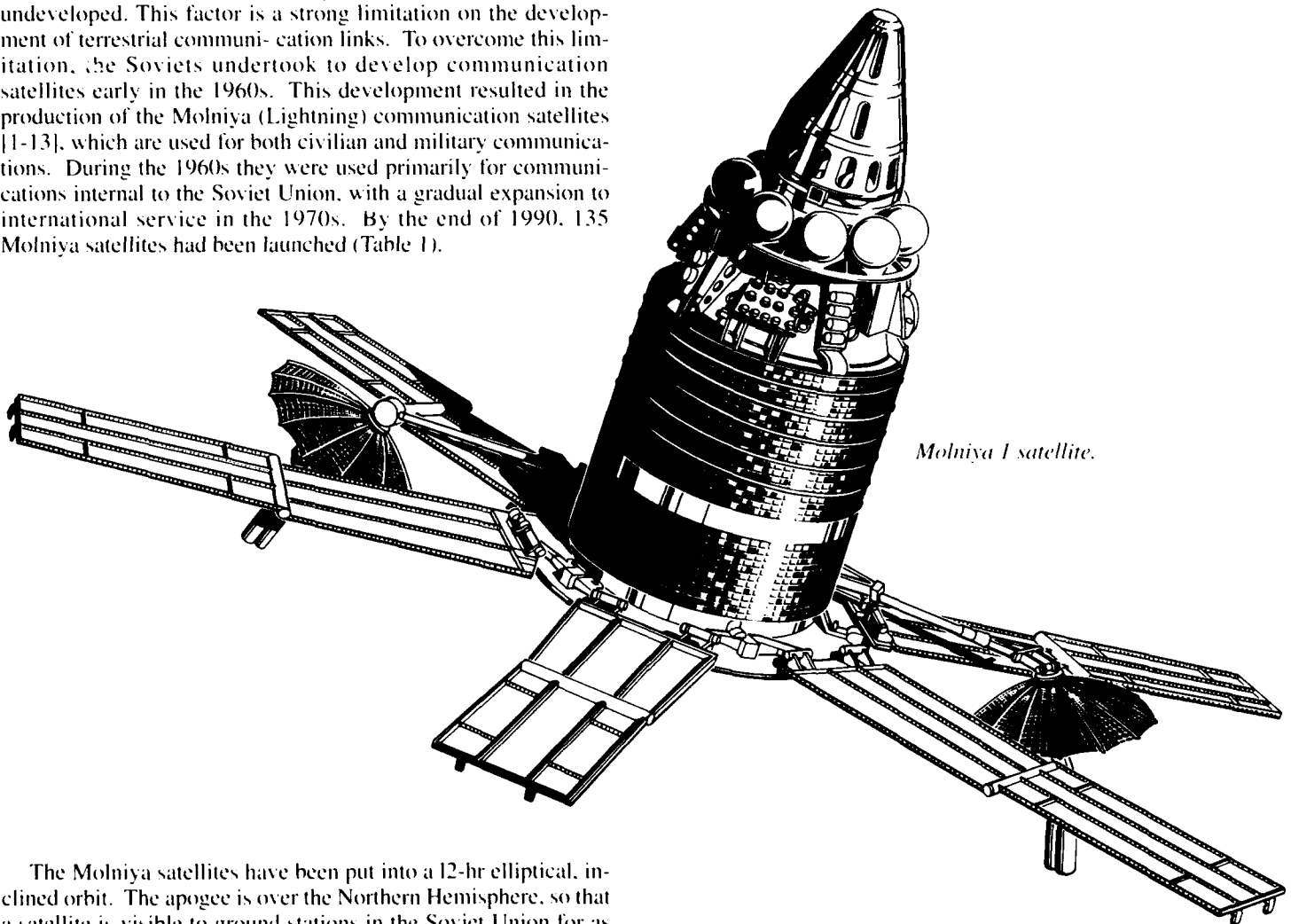
The communication satellites built and launched by the Soviet Union are described here [1-3]. The most well known are the Molniya satellites, of which more than 100 have been launched since 1965. These satellites use a high-inclination elliptical orbit well suited to providing coverage of the Soviet land mass. In 1975, the Soviet Union began launching communication satellites into synchronous orbit. Several types exist, and others, although announced, have yet to be launched. The Soviet Union has also launched radio amateur communication satellites, which are described later.

* * * * *

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2. Congressional Research Service, *Soviet Space Programs, 1971-1975*, U.S. Senate Committee Print, Volume 1, U.S. Government Printing Office, Washington, D.C. (1976).
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MOLNIYA

The Soviet Union has a very large land mass, much of which is undeveloped. This factor is a strong limitation on the development of terrestrial communication links. To overcome this limitation, the Soviets undertook to develop communication satellites early in the 1960s. This development resulted in the production of the Molniya (Lightning) communication satellites [1-13], which are used for both civilian and military communications. During the 1960s they were used primarily for communications internal to the Soviet Union, with a gradual expansion to international service in the 1970s. By the end of 1990, 135 Molniya satellites had been launched (Table 1).



Molniya 1 satellite.

The Molniya satellites have been put into a 12-hr elliptical, inclined orbit. The apogee is over the Northern Hemisphere, so that a satellite is visible to ground stations in the Soviet Union for as much as 9 hr during one orbit, and about 15 hr total per day. The inclination (62-65 deg) permits good visibility to all Soviet ground stations and provides coverage of the polar areas, which is not possible from a synchronous equatorial orbit. The high-inclination orbit is easy to achieve from the high-latitude Soviet launch sites (46° and 63°N), whereas significantly more energy is required for an equatorial orbit.

The Molniya satellites relay signals between ground stations of the Orbita network. Stations that use the frequencies associated with the Molniya 2 and 3 satellites are designated Orbita 2. Orbita ground stations use antennas that are about 40 ft in diameter. Apparently, some functions of the Orbita network have been transferred to the Statsionar satellites in recent years.

Table 1. Mohniya Satellites

SATELLITE SERIES			LAUNCH DATE	DECAY DATE	SATELLITE SERIES			LAUNCH DATE	DECAY DATE
1	2	3			1	2	3		
1			23 April 1965	16 August 1979	43			12 April 1979	9 December 1989
2			13 October 1965	17 March 1967			12	5 June 1979	
3			25 April 1966	11 June 1973	44			31 July 1979	
4			20 October 1966	11 September 1968	45			21 October 1979	
5			24 May 1967	26 November 1971	46			11 January 1980	
6			3 October 1967	4 March 1969	47			21 June 1980	
7			22 October 1967	31 December 1969			13	18 July 1980	
8			21 April 1968	29 January 1974	48			16 November 1980	
9			6 July 1968	15 May 1971			14	9 January 1981	
10			5 October 1968	16 July 1976	49			30 January 1981	
11			11 April 1969	17 April 1974			15	24 March 1981	
12			22 July 1969	18 June 1971			16	9 June 1981	
13			19 February 1970	29 September 1975	50			25 June 1981	
14			26 June 1970	16 February 1976			17	17 October 1981	
15			29 September 1970	20 March 1976	51			17 November 1981	
16			27 November 1970	25 November 1975	52			23 December 1981	
17			25 December 1970	22 December 1975	53			26 February 1982	
18			28 July 1971	19 July 1977			18	24 March 1982	
19	1		24 November 1971	10 May 1976	54			28 May 1982	
20			19 December 1971	13 April 1977	55			21 July 1982	
			4 April 1972	30 January 1974			19	27 August 1982	
	2		19 May 1972	22 March 1977			20	11 March 1983	
	3		30 September 1972	12 January 1978	56			16 March 1983	
21			14 October 1972	1 November 1977	57			2 April 1983	
22			2 December 1972	11 February 1976	58			19 July 1983	
	4		12 December 1972	22 January 1975			21	31 August 1983	
23			3 February 1973	23 October 1977	59			23 November 1983	
	5		5 April 1973	6 January 1979			22	21 December 1983	
	6		11 July 1973	5 August 1978	60			16 March 1984	
24			30 August 1973	5 December 1979	61			10 August 1984	
	7		19 October 1973	8 July 1983	62			24 August 1984	
25			14 November 1973	26 May 1979	63			14 December 1984	
26			30 November 1973	9 June 1985			23	16 January 1985	
	8		25 December 1973	24 November 1984			24	29 May 1985	
27			20 April 1974	17 November 1983			25	17 July 1985	
	9		26 April 1974		64			22 August 1985	
	10		23 July 1974				26	3 October 1985	
28			24 October 1974	29 December 1985	65			23 October 1985	
		1	21 November 1974	15 May 1986	66			28 October 1985	
	11		21 December 1974	7 July 1988			27	24 December 1985	
	12		6 February 1975	4 July 1985			28	18 April 1986	
		2	14 April 1975	29 November 1988			29	19 June 1986	
29			29 April 1975		67			31 July 1986	
30			5 June 1975	12 August 1987	68			5 September 1986	
	13		8 July 1975				30	21 October 1986	
31			2 September 1975	19 November 1986	69			15 November 1986	
	14		9 September 1975		70			26 December 1986	
		3	14 November 1975				31	22 January 1987	
	15		17 December 1975		71			11 March 1988	
		4	27 December 1975	12 August 1986	72			17 March 1988	
32			22 January 1976				32	26 May 1988	
33			11 March 1976		73			12 August 1988	
34			19 March 1976	14 May 1985			33	29 September 1988	
		5	12 May 1976				34	27 December 1988	
35			23 July 1976	29 May 1987	74			28 December 1988	
	16		2 December 1976		75			15 February 1989	
		6	28 December 1976				35	8 June 1989	
	17		11 February 1977		76			27 September 1989	
36			24 March 1977				36	28 November 1989	
		7	28 April 1977		77			23 January 1990	
37			24 June 1977				37	26 April 1990	
38			30 August 1977				38	13 June 1990	
		8	28 October 1977		78			10 August 1990	
		9	24 January 1978	5 December 1989			39	20 September 1990	
39			2 March 1978		79			23 November 1990	
40			2 June 1978		80			14 February 1991	
41			14 July 1978				40	21 March 1991	
42			23 August 1978		81			18 June 1991	
		10	13 October 1978		82			1 August 1991	
		11	18 January 1979				41	17 September 1991	

Molniya 1

The Molniya 1 series of satellites has been in use since 1965. These were the first communication satellites developed by the Soviets; the only thing known about their development is that Cosmos 41 was flown as a test vehicle in 1964. This association was determined after the Molniya satellites began to be launched into the same orbit as Cosmos 41; the Soviets did not admit the relationship until five years after Cosmos 41 was launched.

The Molniya 1 satellites use three-axis stabilization. Both solar panels and antennas are deployed after launch. The gimballed antennas are pointed at the earth while the whole satellite body is rotated to orient the solar array toward the sun.

The Molniya 1 communications subsystem can relay either a single television signal or duplex narrowband (e.g., telephone or telegraph) transmissions. About 40 W output power is used for transmission of a television signal; with narrowband operation, each of the two signals has an output power of about 14 W. The Molniya 1 design has probably been modified several times over the past 20 years. However, many details of the satellites never have been described, so it is impossible to determine how much the design has changed.

The first Molniya 1 was launched in April 1965. During its first day in orbit, television signals were exchanged between Moscow and Vladivostok. In 1966, the first increment of stations in the Orbita ground network became operational. These stations can receive television signals, and both receive and transmit voice, data, and facsimile signals. Moscow and Vladivostok are the two primary stations and are the only ones to transmit television.

The original Molniya 1 constellation had three active satellites; it soon grew to four. In the 1970s, the constellation grew to eight active satellites.

The eight are in two groups of four; each group's orbits have a common ground track, with the satellites spaced six hours apart along the ground track. The apogees of the two groups' ground tracks are separated by 90 deg of longitude.

In the 1970s, some traffic was transferred to the Molniya 2 satellites, then to Molniya 3 and Gorizont satellites. It is now assumed that all civil traffic is on these newer satellites and that Molniya 1s are used only for military and government communications.

Molniya 2

The Molniya 2 satellites evolved from the Molniya 1 satellite; the first launch was in November 1971. The major change was the communication frequencies, which were in the 5.7- to 6.2-GHz band for reception and the 3.4- to 3.9-GHz band for transmission. Molniya 1 satellites use 0.8 to 1.0 GHz for both transmission and reception. Besides the frequency change, it seems that Molniya 2 had a greater communication capacity than Molniya 1. Some, or all, of the Molniya 2 satellites used horn antennas rather than the parabolic reflectors used on Molniya 1 satellites. In both cases, the antenna pattern was approximately earth coverage (approximately 20-deg beamwidth) when the satellite was near apogee. The only obvious change in support subsystems was additional

sections on the Molniya 2 solar array. The last Molniya 2 launch was in February 1977; these satellites have been replaced by the Molniya 3 satellites.

Molniya 3

The first Molniya 3 satellite was launched in November 1974. The basic characteristics of the Molniya 2 and Molniya 3 series seem to be the same, and no explanation has been given for the change in name. Each satellite has three or four transponders in the same frequency bands used by Molniya 2. Transmitter powers per transponder have been reported as being 20, 40, or 80 W. The Molniya 3 satellites were launched to establish a four-satellite constellation, which grew to an eight-satellite constellation in the early 1980s. The satellites handle telephone and television traffic within the Soviet Union and between the Soviet Union and other countries, although the majority of international traffic is probably on the Gorizont satellites.

* * * * *

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Notes:

- a. Early Molnias are sometimes designated 1B, 1C, and so forth, rather than 1-2, 1-3, and so forth.
- b. Cosmos 41, launched in August 1974, was a Molnia prototype.
- c. A discussion of the orbital decay of Molnia satellites may be found in Reference 7.
- d. Launch failures are not identified by the Soviet Union.

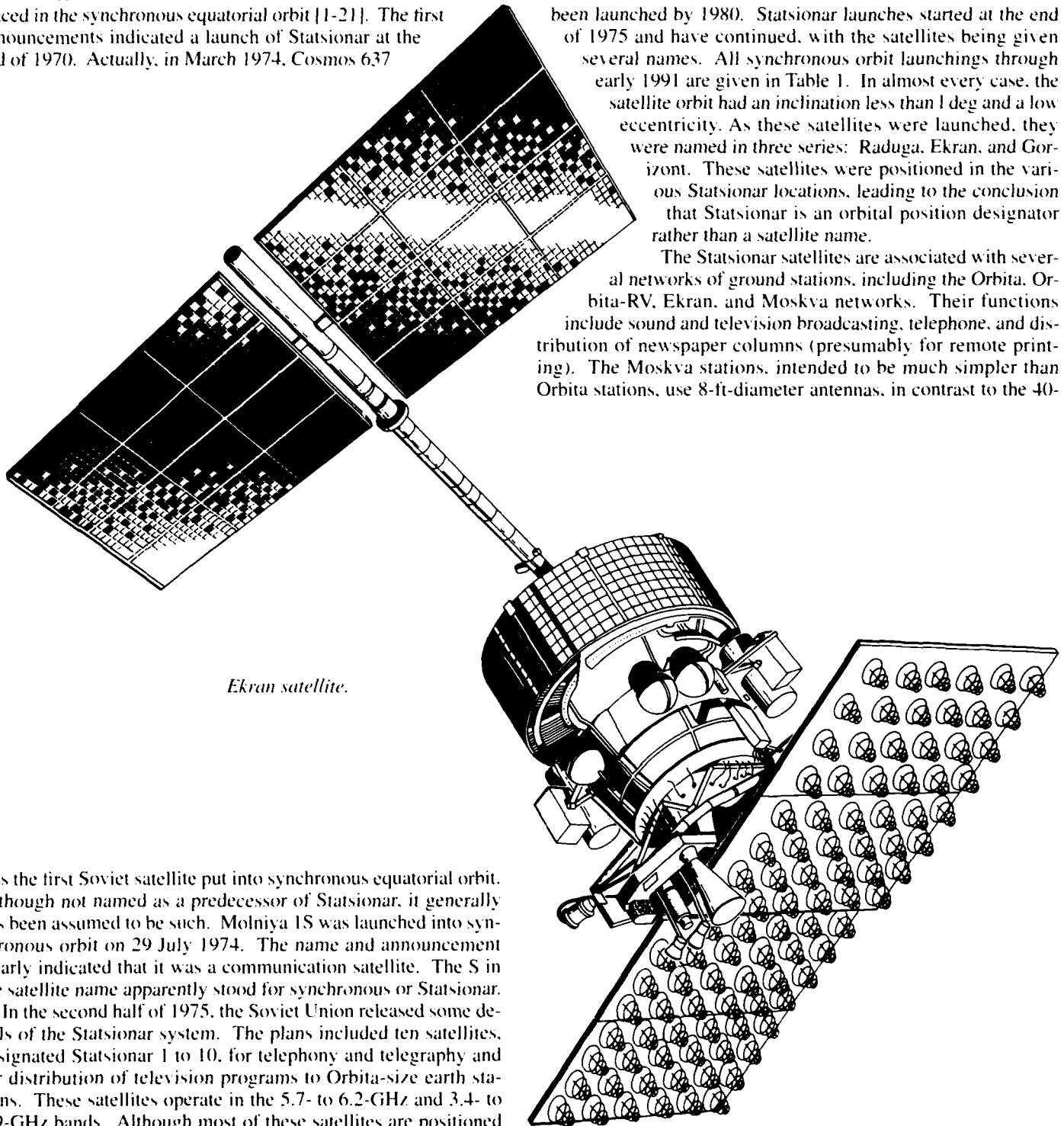
RADUGA, EKRAN, AND GORIZONT

The Molniya satellites all use elliptical, high-inclination orbits. Beginning in 1969, the Soviet Union discussed plans for a communication satellite called Statsionar, which would be placed in the synchronous equatorial orbit [1-21]. The first announcements indicated a launch of Statsionar at the end of 1970. Actually, in March 1974, Cosmos 637

the Orbita type. This satellite has an uplink at 6.2 GHz and a downlink at 714 MHz.

All of the Statsionar satellites announced in 1975 were to have been launched by 1980. Statsionar launches started at the end of 1975 and have continued, with the satellites being given several names. All synchronous orbit launchings through early 1991 are given in Table 1. In almost every case, the satellite orbit had an inclination less than 1 deg and a low eccentricity. As these satellites were launched, they were named in three series: Raduga, Ekran, and Gorizont. These satellites were positioned in the various Statsionar locations, leading to the conclusion that Statsionar is an orbital position designator rather than a satellite name.

The Statsionar satellites are associated with several networks of ground stations, including the Orbita, Orbita-RV, Ekran, and Moskva networks. Their functions include sound and television broadcasting, telephone, and distribution of newspaper columns (presumably for remote printing). The Moskva stations, intended to be much simpler than Orbita stations, use 8-ft-diameter antennas, in contrast to the 40-



Ekran satellite.

was the first Soviet satellite put into synchronous equatorial orbit. Although not named as a predecessor of Statsionar, it generally has been assumed to be such. Molniya 1S was launched into synchronous orbit on 29 July 1974. The name and announcement clearly indicated that it was a communication satellite. The S in the satellite name apparently stood for synchronous or Statsionar.

In the second half of 1975, the Soviet Union released some details of the Statsionar system. The plans included ten satellites, designated Statsionar 1 to 10, for telephony and telegraphy and for distribution of television programs to Orbita-size earth stations. These satellites operate in the 5.7- to 6.2-GHz and 3.4- to 3.9-GHz bands. Although most of these satellites are positioned to serve the Soviet Union and neighboring countries, the system does provide global coverage. Coverage of the Soviet Union itself requires at least two satellites, because the geography is such that the entire country cannot be seen from any one point in synchronous equatorial orbit.

The 1975 announcements also included another satellite, Statsionar T, for television broadcasting to earth stations smaller than

ft-diameter antennas for Orbita. The basic function of both the Ekran and Moskva networks is to expand the population served by television. In 1977, the Soviet Union claimed to have 70 Orbita and 60 Ekran stations in operation with plans for more than 1000 Ekran stations. By the late 1980s, the number in operation was reported to be more than 4000.

Table 1. *Statsionar Satellites*

NAME	DATE	LONGITUDE
Raduga 1	22 December 1975	a
Raduga 2	11 September 1976	a
Ekran 1	27 October 1976	a
Raduga 3	24 July 1977	a
Ekran 2	20 September 1977	a
Raduga 4	18 July 1978	a
Gorizont 1	19 December 1978	a
Ekran 3	21 February 1979	a
Raduga 5	25 April 1979	a
Gorizont 2	5 July 1979	a
Ekran 4	3 October 1979	a
Gorizont 3	28 December 1979	a
Raduga 6	20 February 1980	a
Gorizont 4	14 June 1980	a
Ekran 5	14 July 1980	a
Raduga 7	5 October 1980	a
Ekran 6	26 December 1980	a
Raduga 8	18 March 1980	a
Ekran 7	26 June 1981	a
Raduga 9	21 July 1981	a
Raduga 10	9 October 1981	69° E ^b
Ekran 8	5 February 1982	a
Gorizont 5	15 March 1982	a
Ekran 9	16 September 1982	a
Gorizont 6	20 October 1982	31° W ^b
Raduga 11	26 November 1982	a
Ekran 10	12 March 1983	a
Raduga 12	8 April 1983	72° E ^b
Gorizont 7	30 June 1983	a
Raduga 13	26 August 1983	a
Ekran 11	30 September 1983	a
Gorizont 8	30 November 1983	a
Raduga 14	15 February 1984	75° E ^b
Ekran 12	16 March 1984	a
Gorizont 9	22 April 1984	54° E ^b
Raduga 15	22 June 1984	a
Gorizont 10	1 August 1984	a
Ekran 13	24 August 1984	a
Gorizont 11	18 January 1985	11° W
Ekran 14	22 March 1985	a
Raduga 16	8 August 1985	34° W ^b
Raduga 17	15 November 1985	85° E ^b
Raduga 18	17 January 1986	170° W
Ekran 15	24 May 1986	a
Gorizont 12	10 June 1986	44° E ^b
Raduga 19	25 October 1986	44° E
Gorizont 13	18 November 1986	90° E
Raduga 20	19 March 1987	85° E
Gorizont 14	11 May 1987	103° E
Ekran 16	4 September 1987	a
Raduga 21	10 December 1987	128° E
Ekran 17	27 December 1987	99° E
Gorizont 15	31 March 1988	14° W
Ekran 18	6 May 1988	a
Gorizont 16	18 August 1988	80° E
Raduga 22	20 October 1988	35° E
Ekran 19	8 December 1988	99° E
Gorizont 17	26 January 1989	53° E
Raduga 23	14 April 1989	26° W
Raduga 1-1 ^c	21 June 1989	49° E
Gorizont 18	5 July 1989	140° E
Gorizont 19	28 September 1989	96° E
Raduga 24	15 December 1989	45° E
Raduga 25	15 February 1990	70° E
Gorizont 20	20 June 1990	14° W
Gorizont 21	3 November 1990	90° E
Gorizont 22	23 November 1990	40° E
Raduga 26	20 December 1990	85° E
Raduga 1-2 ^c	27 December 1990	49° E
Gorizont 23	1 July 1991	

^aSatellite has been moved above synchronous orbit, or has failed and is drifting.

^bSatellite probably no longer working.

^cThe significance of this designation has not been announced.

The Intersputnik network for international communications started with the use of Molniya satellites but now uses Statsionar satellites. The Intersputnik network and organization includes most east European and Asian nations plus a few others with close ties to the Soviet Union, such as Cuba. The ground stations are similar to those of the Orbita network.

Raduga

The first Raduga (Rainbow) was launched in December 1975 and identified as being the same as the previously announced Statsionar 1. The Soviet Union announced that the Raduga satellites are three-axis-stabilized and have sun-tracking solar arrays. Other details of their design are unknown but might be similar to the Molniya 3 design. The estimated capacity of a Raduga is about one television signal and up to one thousand duplex voice circuits, when used with 30- to 40-ft-diameter earth station antennas. No photos or models of a Raduga have been displayed by the Soviet Union. The inference is that these satellites primarily or wholly serve the military. This inference is strengthened by reports that, in addition to 6/4-GHz transponders, the Radugas have an 8/7-GHz transponder. This latter band is used only for military satellite communications in the western world and is associated with the Gals system which the Soviet Union announced to be for government and military use.

Ekran

The function of the Ekran (Screen), or Statsionar T, satellites is to broadcast television to rural communities in the northern and Asian regions of the Soviet Union. The Ekran transmitter provides a 200-W output at 714 MHz for a single-frequency modulated signal; newer satellites may have a second 200-W transmitter at 754 MHz. The antenna gain from the 96-element array of helices is 33.5 dB peak and 26 dB at the edge of the service area. Typically, two operational Ekrans are in orbit.

Gorizont

In December 1978, the Soviet Union launched the first Gorizont (Horizon) satellite. Its stated function was television relay. The satellite was not identified in relation to the Statsionar system until the third launch, which was identified as Statsionar 5. The first Gorizont had an elliptical, 11-deg inclination orbit with a 24-hr period, attributed to a launch vehicle malfunction, but subsequent satellites had typical synchronous equatorial orbits. However, the satellite inclination is not controlled as tightly as those of western satellites.

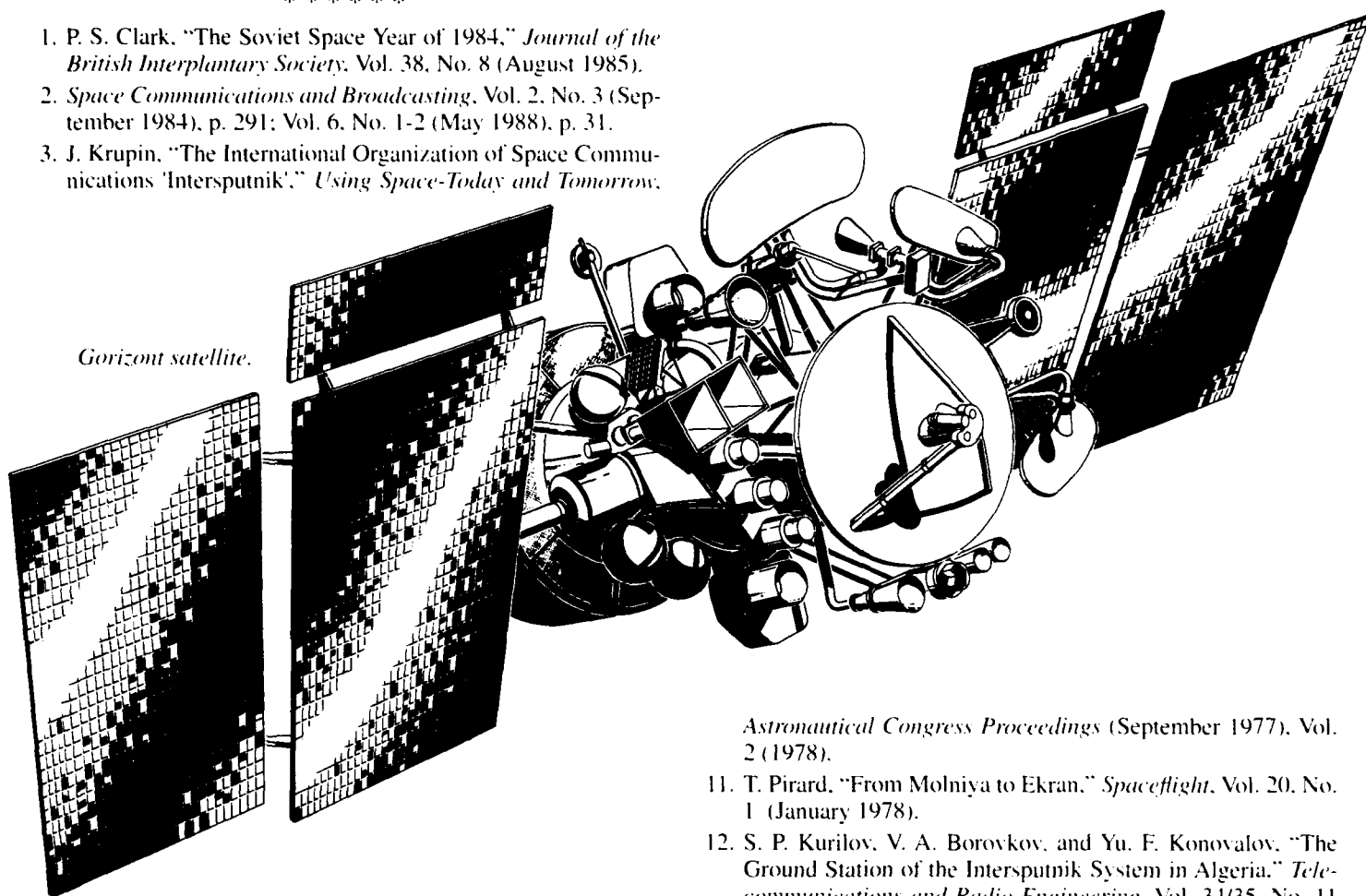
A Gorizont satellite displayed at the 1979 Paris Air Show reveals a three-axis-stabilized satellite (see illustration) whose body shape is very similar to that of Ekran. The satellite has both deployed solar arrays, of a somewhat different configuration than Ekran, plus some body-mounted solar cells. The satellite has several parabolic reflectors and several horn antennas. The horn antennas probably have an earth coverage pattern, the reflectors a narrower beam.

The basic Gorizont satellite apparently has six transponders in the 6-GHz uplink and 4-GHz downlink bands used extensively by other communications satellites. The transmitter power per transponder is similar to that of Molniya, with a maximum of 40 W. Some Gorizont satellites are reported to have other transponders with 14-GHz uplinks and 11-GHz downlinks, and with uplinks and downlinks in the 1.5- to 1.6-GHz band. The latter band is probably associated with a group of four helix antennas seen on some Gorizont displays. The 14/11-GHz and 1.5/1.6-GHz transponders apparently are associated with the Luch and Volna systems, respectively.

* * * * *

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Gorizont satellite.



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GALS, VOLNA, AND LUCH

In 1977, the Soviet Union announced plans for three new communication systems using satellites in synchronous orbit: Gals, Volna, and Luch (or Loutch) [1-4]. A few additional Gals and Volna satellites were announced in subsequent years. Frequency bands and orbital longitudes for these satellites are given in Table 1. Additional Stations orbital positions have been announced to encompass the orbital longitudes that do not correspond to the Stations 1 to 10 series. The coincidences of different systems at various longitudes suggested multiple payloads on a single spacecraft. Cosmos 1738, a synchronous orbit satellite launched in April 1986, may be related to these systems.

Gals (Tack) is a system intended for government service. It uses the 7.25- to 7.75-GHz and 7.9- to 8.4-GHz bands. Gals satellites are described by the Soviet Union as having ten narrow-band channels, with three or four receivers and transmitters. Antenna patterns include earth coverage, Northern Hemisphere, and a spot beam with about 5-deg beamwidth. A few reports have mentioned 7/8-GHz equipment on Raduga satellites, which probably are related to the Gals system.

Table 1. New Synchronous Satellites

NAME	FREQUENCY BAND ^a	LONGITUDE
Volna 1	UHF and L	25°W
Gals 1	X	25°W
Luch P1	11/14 GHz	25°W
Volna 2	L	14°W
Luch 1	11/14 GHz	14°W
Gals 6	X	35°E
Volna 3	UHF and L	45°E
Gals 2	X	45°E
Luch P2	11/14 GHz	45°E
Volna 4	L	53°E
Luch 2	11/14 GHz	53°E
Volna 5	UHF and L	85°E
Gals 3	X	85°E
Luch P3	11/14 GHz	85°E
Luch 3	11/14 GHz	90°E
Volna 8	L	90°E
Gals 5	X	130°E
Volna 6	L	140°E
Luch 4	11/14 GHz	140°E
Volna 7	UHF and L	170°W
Gals 4	X	170°W
Luch P4	11/14 GHz	170°W

^a UHF = 240 to 400 MHz, L-band = 1540 to 1650 MHz, X-band = 7.25 to 8.4 GHz

Volna (Wave) is a system for mobile communications and will be used only by the Soviet Union. All the satellites have L-band equipment with two channels, one for aeronautical service and one for maritime service. The uplink frequencies will be near 1650 MHz, the downlink near 1540 MHz; both will use earth coverage antenna patterns.

The odd-numbered Volnas have the UHF payload which uses the same frequency band associated with Western military communications satellites. The uplinks use 335 to 400 MHz, the downlinks 240 to 328 MHz. These Volnas have announced longitudes similar or identical to actual Raduga longitudes. The conclusion is that Raduga is the basic designation for synchronous orbit military/government communications satellites, and that each particular application corresponds to a frequency band and a payload on the Raduga satellites. A similar correspondence exists between the announced longitudes for the even-numbered Volnas and the actual Gorizont longitudes, suggesting that Gorizont is the overall spacecraft name for civilian synchronous orbit communication satellites. Morya (seaman) is another name applied to satellites for maritime communications, but its relation to Volna is unknown.

The Luch (Beam or Ray) system is intended for commercial communications, both domestic and international. These satellites use the 11- and 14-GHz bands. The Luch system is supposed to consist of four satellites. However, these may turn out to be payloads on four Gorizonts. The first Luch payload was launched in March 1982 on Gorizont 5. It was used in a program of communications and propagation experiments conducted by the Soviet Union and several eastern European nations. Another group of four satellites is called Luch P. The meaning of the P is unknown. However, the general understanding of Luch P is that it uses the same communications equipment as Luch, hence the common name, but that it is for government and military use. This latter conclusion is based on the fact that its longitudes coincide with those of Raduga satellites. It is likely that Luch P will exist as payloads on the Radugas and not as distinct satellites.

* * * * *

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SATELLITE DATA RELAY NETWORK

In 1981, the Soviet Union announced plans for a Satellite Data Relay Network (SDRN) [1-3] similar in concept to the United States Tracking and Data Relay Satellite System. The network uses three satellites, designated east, central, and west (as seen from the Soviet Union). Frequencies for the network are between

11 and 15 GHz. In 1986, the Soviets announced that a ground control center was communicating with the low-altitude Mir space station through this network, using Cosmos 1700 as the relay satellite. The next satellite in the series probably was Cosmos 1897. Other synchronous orbit satellites, numbered earlier and

later in the Cosmos series, also might be part of a data relay network. It is not clear whether SDRN refers to all, or only to a part, of the Soviet Union's data relay satellites. Potok (Stream) is a name sometimes associated with data relay satellites, but its scope is uncertain.

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CANADIAN AND UNITED STATES SATELLITES

Outside of the Soviet Union, the first domestic (one-country) communication satellite system was that of Canada, which began operating in 1973 and has evolved through several generations of satellites. The first United States domestic communication satellite (often called domsat) system began operating in 1974. Since then, several other systems have been established, and a considerable industry of supplies and services has been created around them. Thus, the United States domsat marketplace is characterized by diversity and competition in many aspects. Economics is certainly the driving force in the United States domsat market. In

contrast, although economics is of concern in Canada, a predominant force is that there is no other practical communications medium available for much of Canada.

The Canadian and United States domsats are described here as well as the United States Marisat satellite and the Tracking and Data Relay Satellite System. The joint Canadian and United States development of a system to serve land-mobile users also is described. Finally, the continuing efforts toward high-power domestic television broadcast satellites are reviewed.

CANADA

In 1969, the Canadian government established the Telesat Canada Corporation. Telesat is intended to provide domestic communication services using satellites [1-8]. Canada has excellent microwave communication facilities, but they are concentrated primarily in the heavily populated region along the Canadian-United States border. In the more northerly regions of Canada, there are hundreds of smaller towns and outposts not served by microwave. Their contact with each other and with the commercial and governmental centers in the south depended on radio-telephone and aircraft services. The radio communication facilities had been difficult to provide and unreliable. The Telesat system now provides television and telephone service to many of these remote places as well as supplementing terrestrial systems for high-density traffic links and television distribution in southern Canada.

The Telesat system began operations at the beginning of 1973 following the launch of the first Anik satellite. (Anik is the Eskimo word for brother.) As plans developed for newer satellites, the first three satellites were designated the Anik A series. The satellites provided all types of communication services throughout Canada. A single Anik B satellite supplemented the A series and provided additional experimental channels. The Anik D series has replaced the A satellites. The Anik C satellites also are in use but have a different function—to augment terrestrial communications on high traffic density paths, and to use the 12- and 14-GHz frequencies for service to terminals in urban areas, where the 4- and 6-GHz bands, used in Anik D, are unacceptable because of

interference from other uses of the band. Development of the Anik E satellites began at the end of 1986. They are dual-frequency band replacements for both Anik C and D satellites.

* * * * *

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Anik A

The Anik A satellites [1-16] were spin-stabilized with a single despun communications antenna. All equipment were mounted within the spinning body. The antenna was a 5-ft-diameter framework, to which was attached a lightweight mesh that was optically transparent but reflective at the communication frequencies. A multiple-element feed horn illuminated the reflector so that the antenna beam was shaped to match the Canadian land mass.

The Anik A communication subsystem had twelve channels and was derived from the Intelsat IV communication subsystem. It had redundant receivers common to all channels and a single 5-W TWT for each channel. Each channel could handle one television signal or as many as 960 one-way telephone circuits. Enough prime power was available to operate all twelve channels initially and up to ten during eclipse and later in the orbital life. Although

the TWTs are not redundant, it was expected that ten of the twelve would still be operable at the end of the seven-year design life. In practice, approximately seven years after launch, each satellite had six TWT failures, which were defined by about 6 dB loss of gain. The satellite and the communication subsystem details are as follows:

Satellite

Cylinder, 75-in. dia., 67-in. height (139 in. overall)

655 lb in orbit, beginning of life

Solar cells and NiCd batteries, 330 W maximum beginning of life, 260 W at end of life

Spin-stabilized, 100 rpm, ± 0.1 -deg accuracy

Solid rocket motor for apogee maneuver, hydrazine propellant for on-orbit use

Configuration

Twelve 36-MHz bandwidth single-conversion repeaters

Capacity

960 one-way voice circuits or one TV program per repeater

Transmitter

3702 to 4178 MHz

One TWT per repeater

5-W output, 33-dBW minimum ERP per repeater over all of Canada

Receiver

5927 to 6403 MHz

Two chains (one on, one standby), each with tunnel diode amplifiers and a low-level TWT

7.8-dB noise figure

Antenna

One 60-in.-dia. offset-fed parabola, linear polarization, beam shaped to maximize gain over Canadian territory, approximately $3^\circ \times 8^\circ$ beamwidth, beam center tilted 7.85° north of equatorial plane

Design life

Seven years

Orbit

Synchronous equatorial, stationkeeping to $\pm 0.1^\circ$ N-S and E-W

Orbital history

1: launched 9 November 1972, in use until 1982, moved above synchronous orbit

2: launched 20 April 1973, in use until 1983, moved above synchronous orbit

3: launched 7 May 1975, in use until fall 1984, moved above synchronous orbit

Delta 1914 launch vehicle (1, 2); Delta 2914 (3)

Management

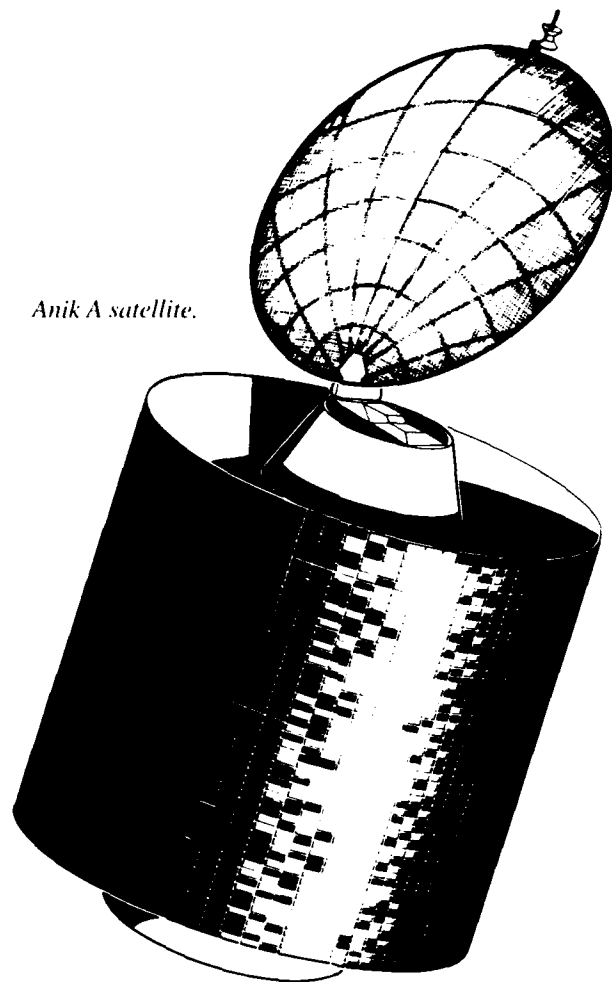
Developed by Hughes Aircraft Company for Telesat Canada

Operated by Telesat Canada

Anik A1 was launched in November 1972 and became operational in January 1973. Originally, seven or eight channels were in full-time use, with other channels in occasional use. Anik A2 was launched in April 1973, primarily as an on-orbit spare for Anik A1. Some channels were leased to United States communications companies for domestic operations prior to the launching of the United States satellites. Although the Anik A antenna pattern was optimized for Canada, the channel capacity between two terminals in the middle or northern latitudes of the United States was still about 60% of the capacity achievable between Canadian terminals.

Anik A3 was launched in 1975 and soon became the primary operational satellite replacing Anik A1. The Anik A1 and A2 satellites provided redundancy as well as channels for occasional transmissions. In July 1979, Anik B became the primary operational satellite. In 1980, Anik A2 was moved to the same longitude as Anik A3, which maximized, at one location, the number of channels available for spare and occasional use. (The single loca-

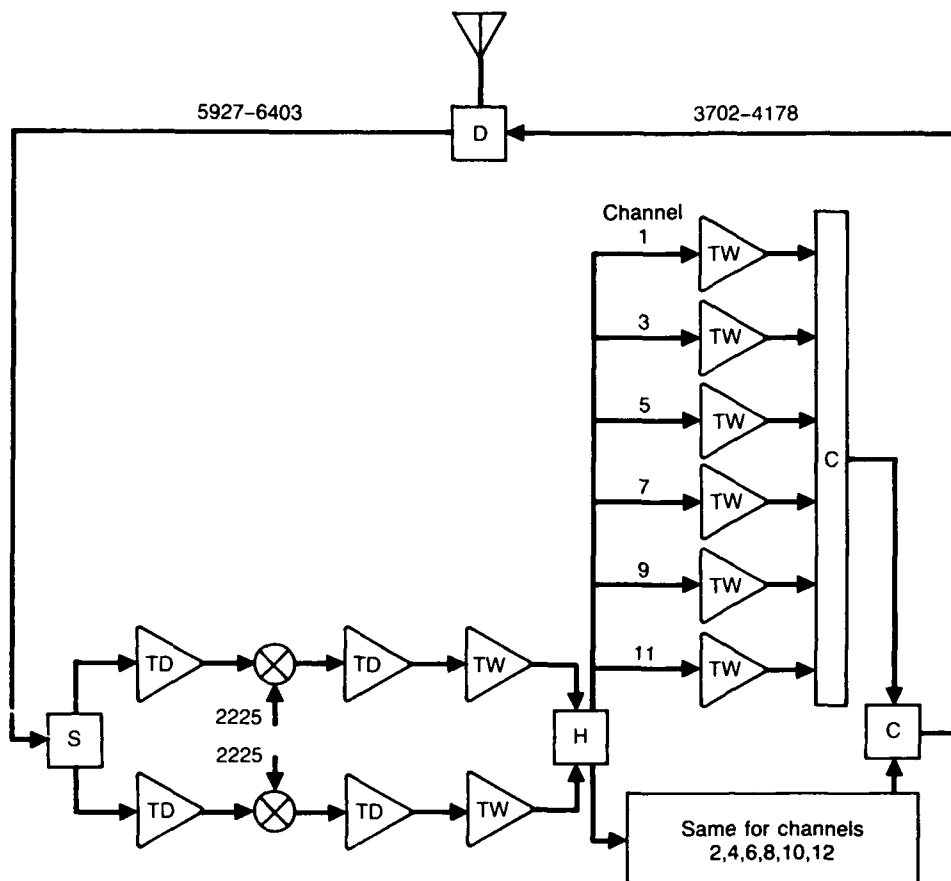
Anik A satellite.



tion minimized the number of ground terminal antennas required.) Between 1982 and 1985, with the Anik D satellites coming into use, the Anik A satellites were turned off and moved out of geosynchronous orbit.

* * * * *

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Anik B

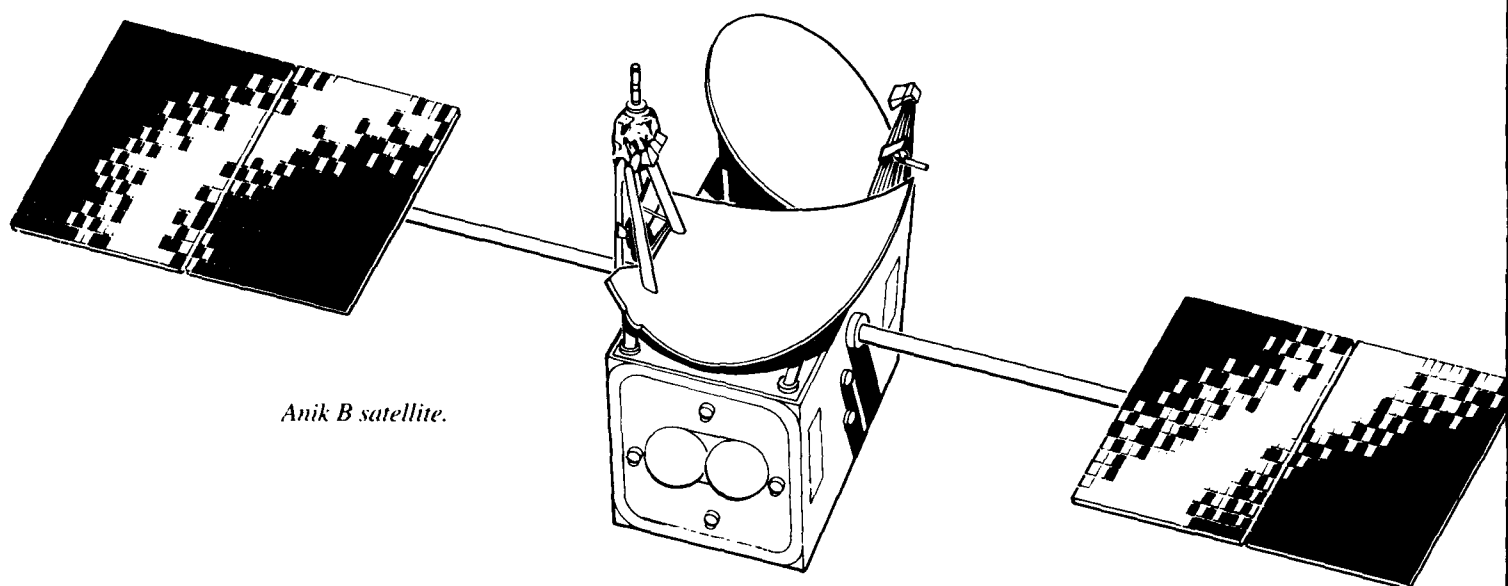
Anik B [1-13] was a single satellite similar in design to the Radio Corporation of America (RCA) United States domestic satellites. It had three-axis stabilization and solar arrays that deployed in orbit. Anik B had two communication subsystems, each with its own antenna. One, which used 4 and 6 GHz, was identical to that of the Anik A satellites, except that the TWT power had been doubled, increasing the ERP by 3 dB, and the gain-to-noise-temperature ratio (G/T) had been increased 1 dB. The other operated at 12 and 14 GHz and made extensive use of hardware developed and tested in the CTS program. It had six channels, four TWTs, and four regional transmitting beams. Together, the four beams covered all of Canada. A number of switches provided flexibility in assigning channels to the regions and minimizing loss of cover-

age resulting from TWT failures. The receiver was connected to a single Canadian coverage beam.

Anik B was launched in December 1978. In July 1979, traffic from Anik A3 was transferred to the 4/6-GHz subsystem. Beginning in 1983, the traffic was split between Anik B and Anik D1. The 12/14-GHz subsystem was leased to the government's Department of Communications. It was used to continue some of the experiments started with CTS and to provide preoperational experience for Anik C services. Anik B was removed from service in the fall of 1986. The satellite details are as follows:

Satellite

Rectangular body with deployed solar arrays, overall span 376 in. (31.3 ft), 128-in. height (body plus antenna)



Anik B satellite.

1016 lb in orbit, beginning of life

Sun-tracking solar array and NiCd batteries, 840 W beginning of life, 635 W minimum after seven years

Three-axis-stabilized, 0.25-deg antenna pointing accuracy (3σ)

Solid rocket motor for apogee maneuver, hydrazine propellant for on-orbit use

Configuration

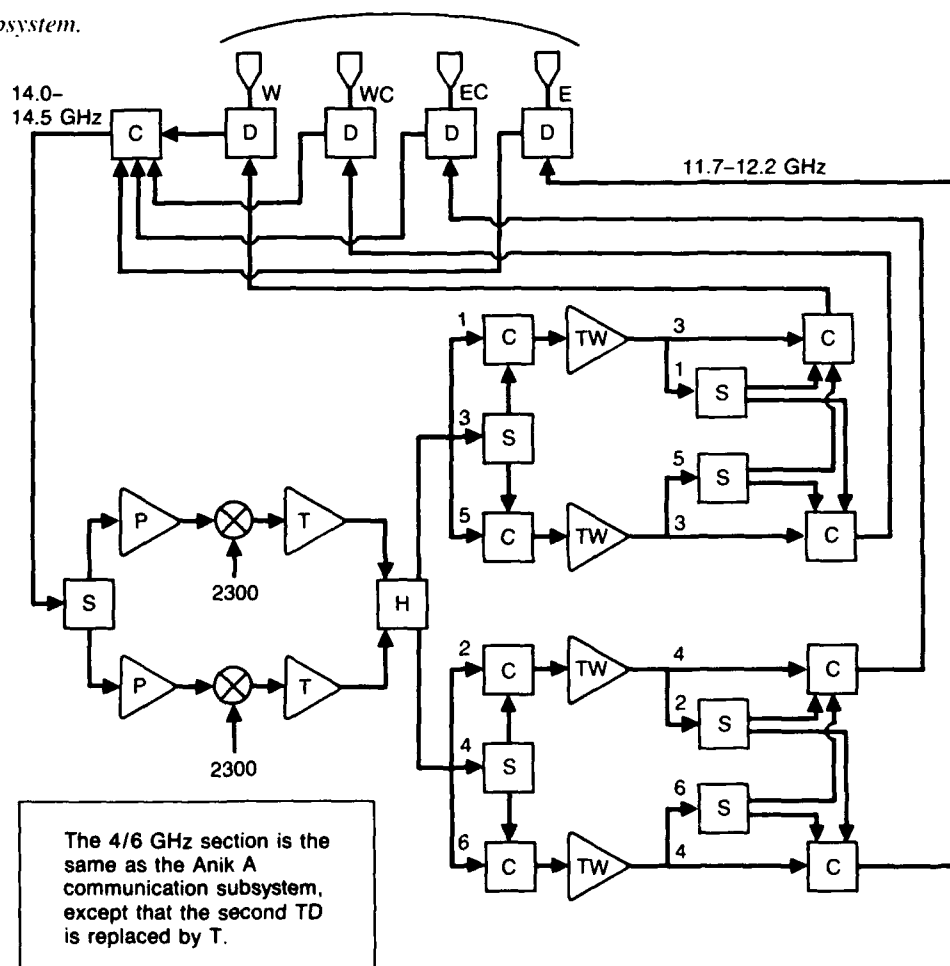
4/6 GHz: twelve 36-MHz bandwidth single-conversion repeaters

12/14 GHz: six 72-MHz bandwidth single-conversion repeaters

Transmitter

4/6 GHz: 3702 to 4178 MHz, one 10-W TWT per repeater, 36-

Anik B 12/14-GHz communication subsystem.



dBW minimum ERP per repeater over all of Canada

12/14 GHz: 11,700 to 12,180 MHz, four 20-W TWTs, 46.5-dBW minimum ERP in each beam

Receiver

4/6 GHz: 5927 to 6403 MHz, $G/T \geq -6$ dB/K

12/14 GHz: 14,000 to 14,480 MHz, $G/T \geq -1$ dB/K

Antenna

4/6 GHz: offset-fed parabola, approximately $3^\circ \times 8^\circ$ beam shaped to match Canadian land mass

12/14 GHz: offset-fed parabola, approximately $36^\circ \times 48^\circ$ in.; one receive beam shaped to match Canada, four 1.8- \times 2.0-deg transmit beams each covering 25% of Canada, minimum measured gain over coverage areas 35.1 dB (transmit) and 29.4 dB (receive)

Design life

Seven years

Orbit

Synchronous equatorial, stationkeeping to $\pm 0.1^\circ$ N-S and E-W

Orbital history

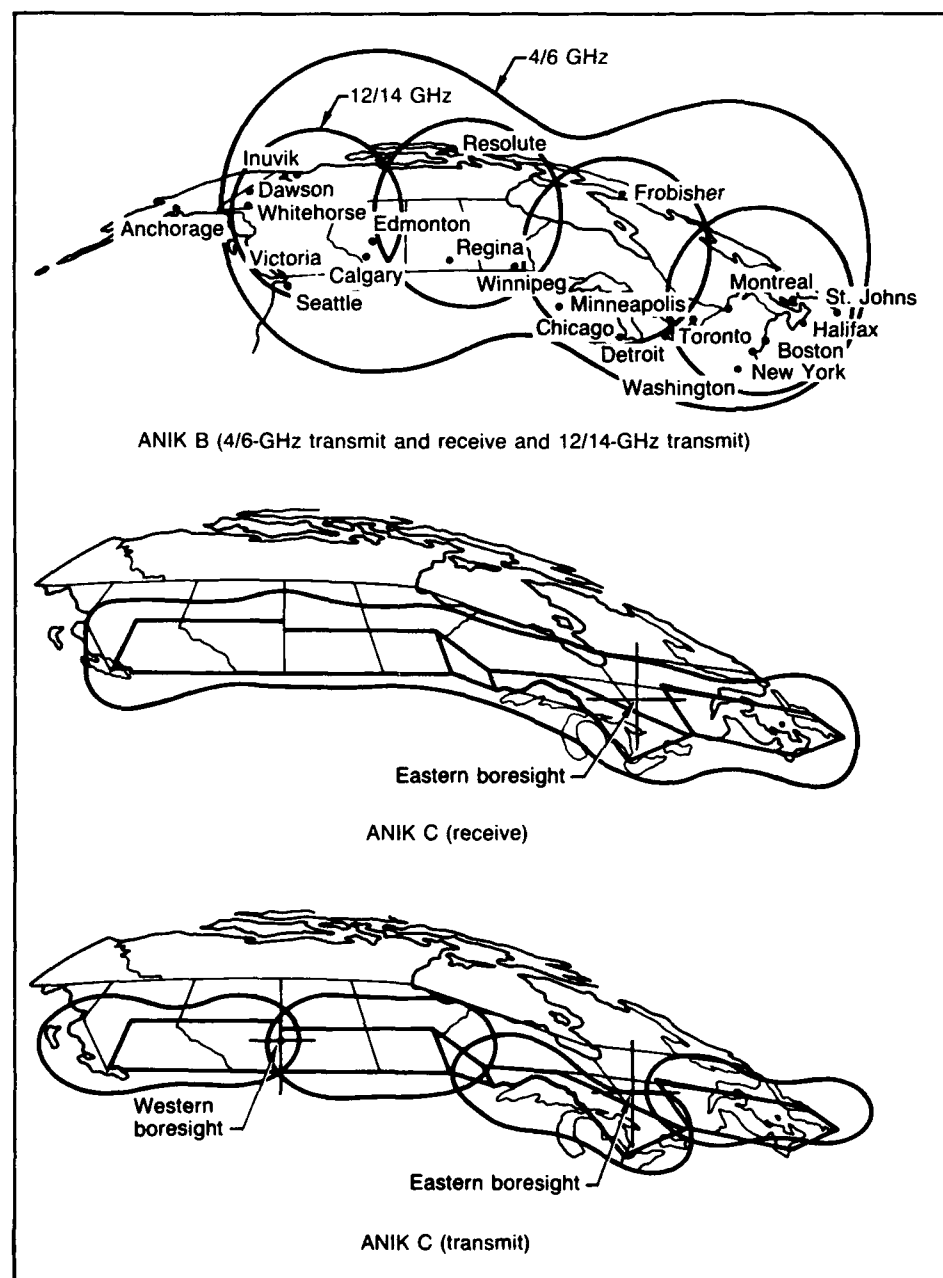
Launched 15 December 1978, operational until fall 1986, moved above synchronous orbit

Delta 3914 launch vehicle

Management

Developed for Telesat Canada by RCA (spacecraft and integration) and Spar Technology, Canada (communication subsystems)

Operated by Telesat Canada



Anik B and C antenna patterns.

1. N. G. Davies, J. W. B. Day, and M. V. Patriarche, "The Transition from CTS/Hermes Communications Experiments to Anik-B Pilot Projects," *EASCON '78 Conference Record* (September 1978).
2. A. Casey-Stahmer, "From Satellite Experiments to Operational Applications: Canadian Experiences and Plans," *Acta Astronautica*, Vol. 8, No. 1 (January 1981).
3. J. W. B. Day, N. G. Davies, and R. J. Douville, "The Applications of Lower Power Satellites for Direct Television Broadcasting," *Acta Astronautica*, Vol. 7, No. 12 (December 1980).
4. R. R. Bowen, et al., "The Development of a Canadian Broadcasting Satellite System at 12 GHz," Paper 51.3, *International Conference on Communications: ICC '80* (June 1980).
5. J. Almond, "Commercial Communication Satellite Systems in Canada," *IEEE Communications Magazine*, Vol. 19, No. 1 (January 1981).
6. R. W. Hoedemaker and D. G. Thorpe, "Anik B, The New Canadian Domestic Satellite," Paper 9/3, *WESCON Technical Papers* (September 1976).
7. R. W. Hoedemaker and D. G. Thorpe, "Anik B, The New Canadian Domestic Satellite," *RCA Engineer*, Vol. 23, No. 1 (June-July 1977).
8. A. R. Raab and K. Farrell, "A Shaped Beam Multifield 14/12 GHz Antenna for Anik-B," *1978 AP-S International Symposium* (May 1978).
9. G. Gothe, "The Anik-B Slim TDMA Pilot Project," Paper 71.4, *National Telecommunications Conference: NTC '80* (November 1980).
10. J. G. Chambers, "An Evolutionary Approach to the Introduction of Direct

Broadcast Satellite Service," Paper 73.2, *National Telecommunications Conference: NTC '80* (November 1980).

11. D. E. Weese, "The Canadian Domestic Satellite Communication System—Present and Future," Paper 7-3, *EASCON '77 Conference Record* (September 1977).

12. R. M. Lester, "Telesat Canada Plans for New Satellite Systems," Paper 78-544, *AIAA 7th Communications Satellite Systems Conference* (April 1978). Revised version in *Journal of Spacecraft and Rockets*, Vol. 17, No. 2 (March-April 1980).
13. O. S. Roscoe, "Satellite Broadcasting in Canada," *SMPTE Journal*, Vol. 91, No. 12 (December 1982).

Anik C

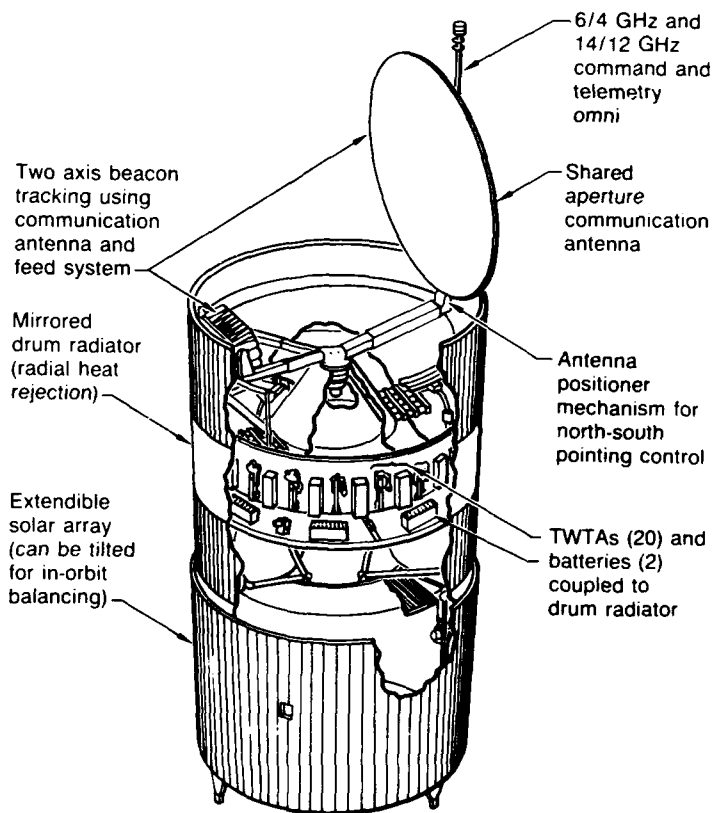
Anik C [1-8] is a spin-stabilized satellite that is designed for launch by either a Delta vehicle or the Space Shuttle. When in orbit, the antenna is deployed from one end of the satellite, and a cylindrical solar panel is extended at the opposite end. Within this panel is the cylindrical body of the satellite, which is also covered with solar cells except for a mirrored band that is a thermal radiator. The combination of the two arrays provides adequate power for the mission and permits a compact launch configuration. The two panels spin together in orbit as a rigid body. The relative position can be varied slightly by ground command to balance the satellite to help maximize antenna pointing accuracy.

The communication subsystem has 16 repeaters and uses the 12- and 14-GHz bands. Both this subsystem and the antenna are mounted on a despun platform within the satellite body. Each repeater has a single TWT and the satellite has four spare TWTs. The TWTs are connected in a ring arrangement so that the spares are available to all channels. The repeaters occupy the 500-MHz allocation twice by means of orthogonal polarizations for both transmission and reception. Each repeater has a bandwidth of 54 MHz, selected to accommodate 90 Mbps digital telephone trunks, yet also to maximize the number of repeaters for maximum flexibility in distribution of television. The antenna is composed of two surfaces, each transparent to one polarization and reflecting another. These surfaces are slightly offset from each other to allow separate feed networks for each polarization.

The channels may be connected in various ways to the four regional transmitting beams. There is a single receive beam. For both reception and transmission, the beams cover only the southern half of Canada, inasmuch as Anik C is used to interconnect only the urban centers of Canada. The use of 12 and 14 GHz allows the ground terminals to be placed inside cities without interference between the satellite system and terrestrial microwave facilities. Furthermore, the use of multiple beams, each covering only a portion of Canada, increases the effective radiated power of the satellite. This is complementary to the beams of Anik A and D, which, covering all of Canada, are best suited to distribution of national television or message services that require nationwide access. In typical use, the Anik Cs will have one 90-Mbps data stream or two FM television signals per satellite repeater.

Development began in April 1978, and Anik C3 was launched on Shuttle Flight 5 in November 1982. It was launched first because the others were put in ground storage, awaiting launch vehicle availability, and it was easier to launch C3 than to store it and remove another from storage. The second satellite was launched in June 1983 and the third in April 1985. Satellites C3 and C2 were put into operation after initial testing in orbit. Traffic did not grow as much as expected when Anik C was planned. Therefore, Satellite C1 was put into orbital storage and offered for sale. A purchase agreement was made in 1986 by a group that planned to use it for transpacific services, but the agreement was cancelled in 1987. By 1989, Telesat began to use the satellite in a

limited way, and in 1990, additional traffic was transferred to it in preparation for the introduction of Anik E1. The satellite details are summarized as follows:



Anik C satellite details.

Satellite

Cylinder, 85-in. dia., 253-in. height (21.1 ft) in deployed condition

1250 lb in orbit, beginning of life

Solar cells and NiCd batteries, 800 W end of life

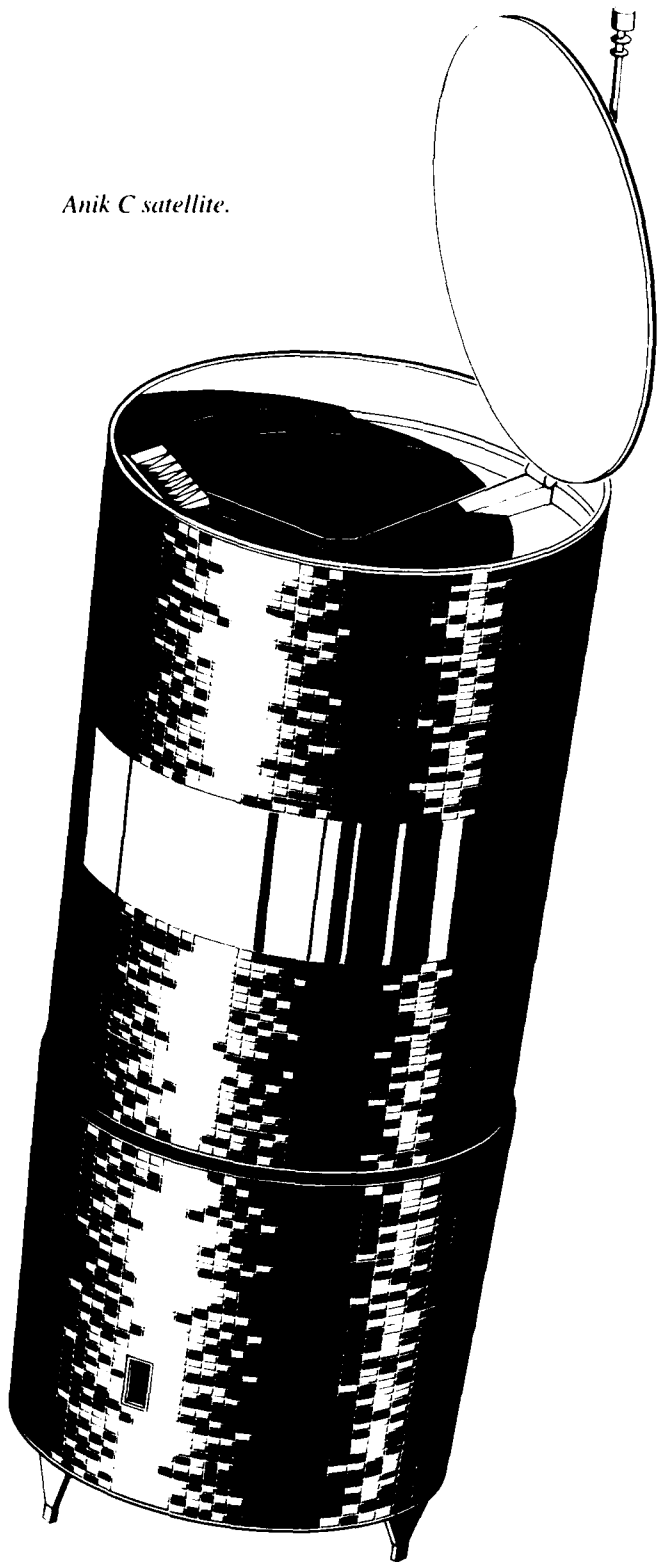
Spin-stabilized, gyrostat, antenna beam pointing to 0.02 deg

Solid rocket motor for apogee maneuver, hydrazine propellant for on-orbit use

Configuration

Sixteen 54-MHz bandwidth repeaters, dual-polarization frequency reuse, horizontal polarization channel centers 13 MHz higher than vertical polarization

Anik C satellite.



Capacity

90 Mbps (1344 voice channels) or two TV programs per repeater

Transmitter

11.703 to 12.197 GHz

One 15-W TWT per repeater plus four spares per satellite
48-dBW ERP per repeater using one antenna beam, 3 dB lower when output is split between two beams, 5.5-dB backoff when two TV transmissions share a repeater

Receiver

14.003 to 14.497 GHz

Two active plus three spare receivers

+3 dB/K G/T over 95% of coverage, otherwise +2 dB/K

Antenna

One 72-in.-dia. paraboloid, dual linear polarizations for both receive and transmit, one receive beam approximately 1×8 deg, four contiguous transmit spot beams approximately 0.8×2 deg each, each pair of spot beams may be combined into an area beam approximately 1.2×2 deg, beams aimed to cover southern half of Canada

Design life

Ten years

Orbit

Synchronous equatorial, stationkeeping to $\pm 0.05^\circ$ N-S and E-W

Orbital history

3: launched 11 November 1982 (deployed from Shuttle, 11 November) 115° W longitude, in use

2: launched 18 June 1983 (deployed from Shuttle, 18 June) 110° W longitude, in use

1: launched 12 April 1985 (deployed from Shuttle, 13 April), 107° W longitude, in use

Shuttle launch vehicle (satellite design is also compatible with Delta 3910)

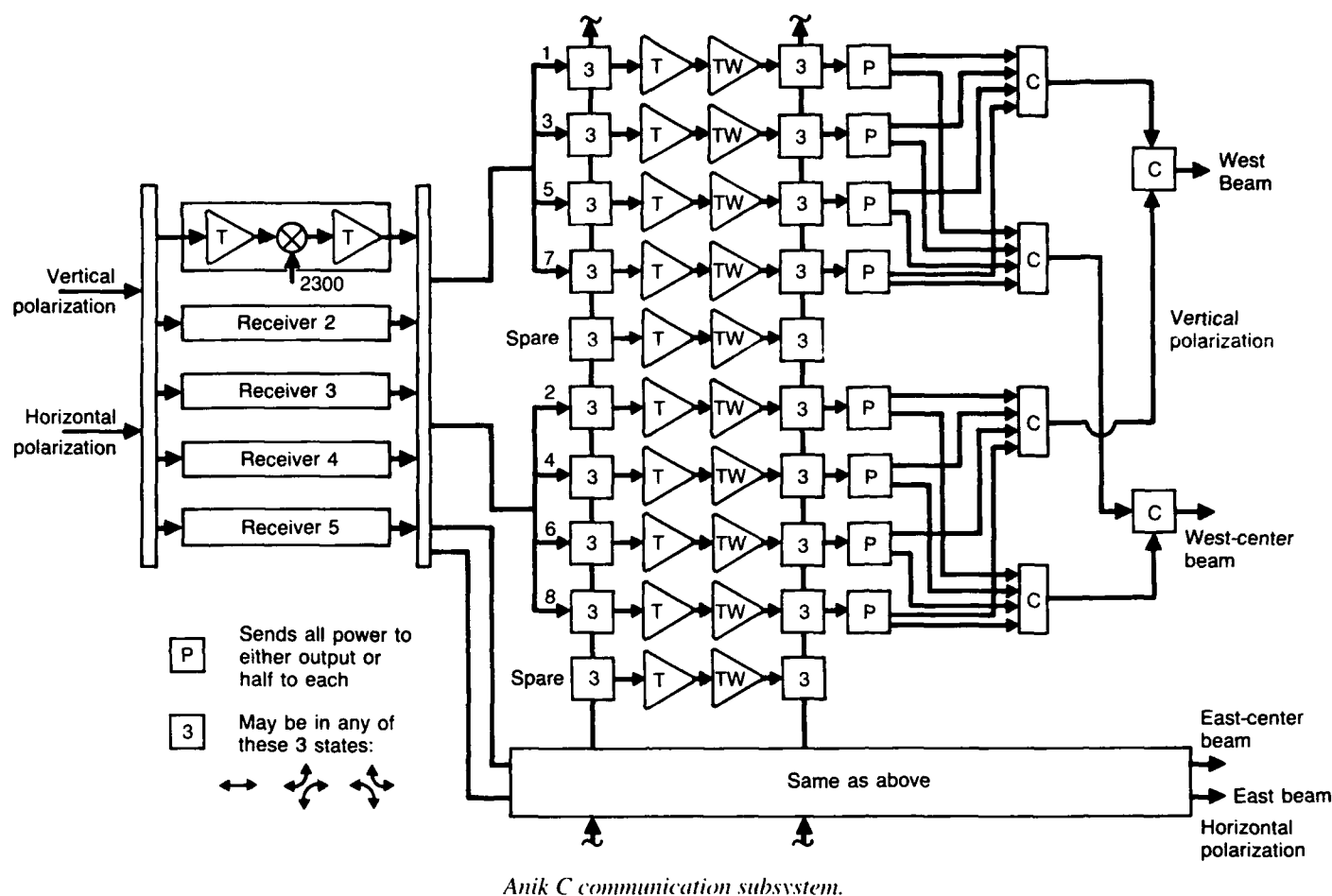
Management

Developed for Telesat Canada by Hughes Aircraft Company (about 40% of the work is subcontracted to Canadian firms)

Operated by Telesat Canada

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1. J. Almond, "Commercial Communication Satellite Systems in Canada," *IEEE Communications Magazine*, Vol. 19, No. 1 (January 1981).
2. D. E. Weese, "The Canadian Domestic Satellite Communication System - Present and Future," Paper 7-3, *EASCON '77 Conference Record* (September 1977).
3. R. M. Lester, "Telesat Canada Plans for New Satellite Systems," Paper 78-544, *AIAA 7th Communications Satellite Systems Conference* (April 1978). Revised version in *Journal of Spacecraft and Rockets*, Vol. 17, No. 2 (March-April 1980).
4. F. H. Smart, "The Anik C 90 Mb/s Digital Service," *Fourth International Conference on Digital Satellite Communications* (October 1978).
5. W. Zatychech, "Anik C Space Segment for Telesat Canada," Paper 80-0474, *AIAA 8th Communications Satellite Systems Conference* (April 1980).
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7. J. R. Campbell and M. Zuliani, "System Design for the TCTS Integrated Satellite Business Network," Paper B2.1, *International Conference on Communications: ICC '83* (June 1983).
8. F. H. Smart, "Overview of the Anik C Satellites and Services," Paper 7.1, *First Canadian Domestic and International Satellites Communications Conference* (June 1983).



Anik D

The Anik D satellites [1-7] are replacements for the Anik A satellites and eventually also for Anik B. The satellite structure, support subsystems, thermal radiator, and deployable solar array are almost identical to those of Anik C.

The major difference between the two satellites is the communication subsystem. Anik D has 24 repeaters in the 4- and 6-GHz bands—twice the number contained in an Anik A satellite and accomplished by dual-polarized reception and transmission. The antenna pattern is shaped to provide coverage of all of Canada, the same as Anik A. However, the TWT output power is twice that of the earlier satellites, thus permitting equal service to smaller ground terminals. The satellite details are as follows:

Satellite

Cylinder, 85-in. dia., 258-in. height (21.5 ft) in deployed condition

Approximately 1400 lb in orbit, beginning of life

Solar cells and NiCd batteries, 800 W end of life

Spin-stabilized, gyrostat

Solid rocket motor for apogee maneuver, hydrazine propellant for on-orbit use

Configuration

Twenty-four 36-MHz bandwidth repeaters, dual-polarization frequency reuse

Capacity

960 one-way voice circuits or one TV program per repeater

Transmitter

3702 to 4198 MHz

One TWT per repeater

10-W output, 36 dBW minimum ERP per repeater over all of Canada

Receiver

5927 to 6423 MHz

Two active plus two spare receivers

G/T ≥ -6 dB/K

Antenna

One 72-in.-dia. reflector, multiple feed horns to optimize beam shape for Canada, orthogonal linear polarizations

Design life

Ten years

Orbit

Synchronous equatorial, stationkeeping to $\pm 0.05^\circ$ N-S and E-W

Orbital history

1: launched 27 August 1982, 105°W longitude, in use
 2: launched 8 November 1984 (deployed from Shuttle, 9 November), 111°W longitude, in storage until 1986, in use since
 Delta 3920 launch vehicle for 1, Shuttle for 2

Management

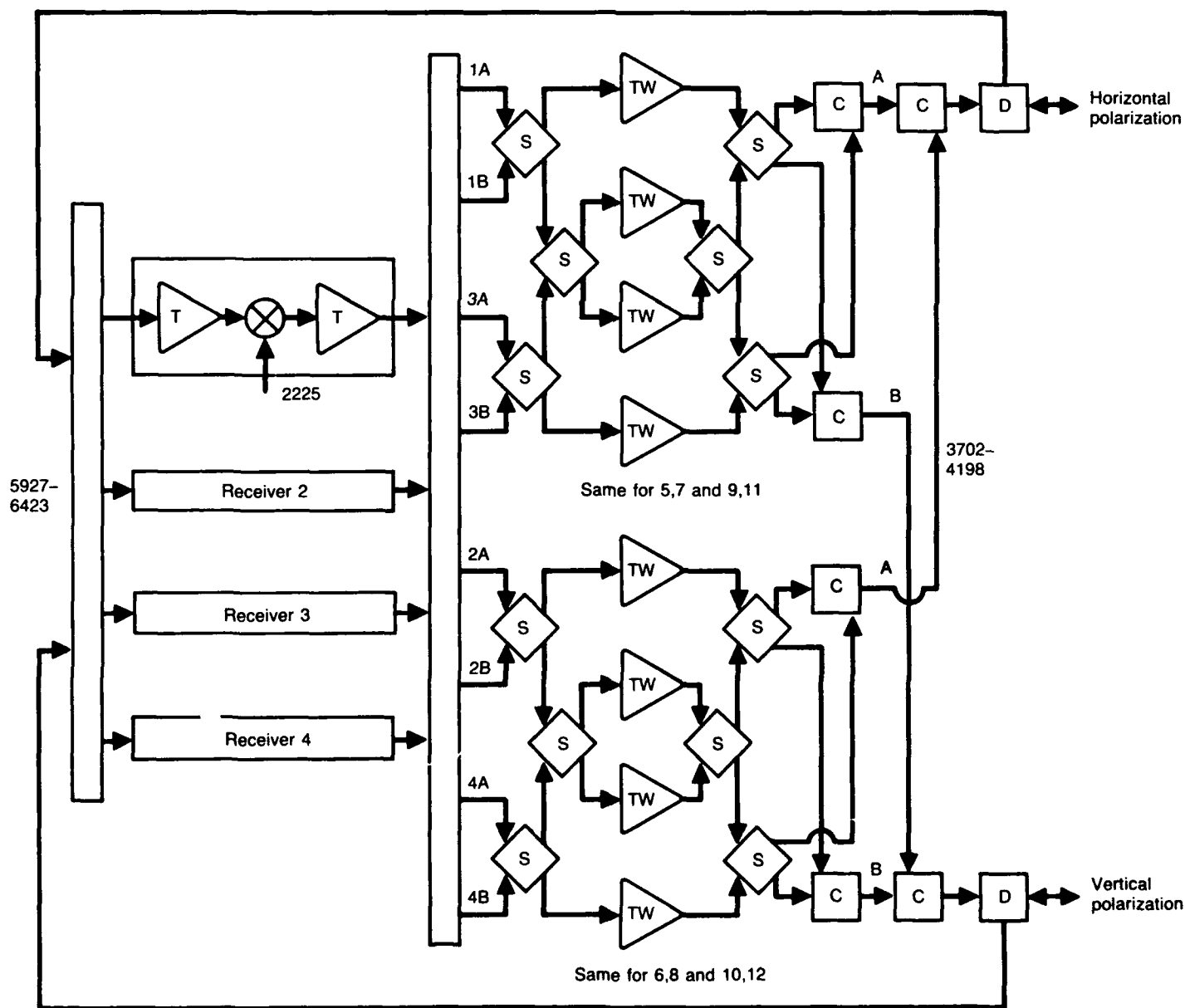
Developed for Telesat Canada by Spar Aerospace with Hughes Aircraft Company as a major subcontractor

Operated by Telesat Canada

The Anik D satellites were built by Spar Aerospace, a Canadian company, which is a subcontractor on many other satellites (including Anik C) of similar design. The first Anik D was launched in August 1982 and is in use. Most 6/4-GHz television service is on Anik D1, whereas message and voice service was predominantly handled via Anik B. The second was launched in November 1984 and put into orbital storage. Telesat saw three benefits to orbital storage: lower launch costs on early Shuttle

flights; availability of space on a Shuttle, when later years' schedules were crowded; and ability to bring the satellite into service, at any time, with only a few days delay. Anik D2 was brought into service in 1986 to take the traffic from Anik B as it reached the end of its useful life. Traffic from both D1 and D2 was transferred to Anik E in 1991. After that, Anik D2 will be a spare and Anik D1 might be retired.

1. R. M. Lester, "The Introduction of New Satellites to an Operating System," Paper 58.2, *International Conference on Communications: ICC '81* (June 1981).
2. J. Almond, "Commercial Communication Satellite Systems in Canada," *IEEE Communications Magazine*, Vol. 19, No. 1 (January 1981).
3. A. R. Smalley, "Overview of Anik D Satellite and Services," Paper 7.2, *First Canadian Domestic and International Satellite Communications Conference* (June 1983).



Anik D communication subsystem.

4. D. L. Doan, et al., "Anik D, Brasilsat and GStar Shaped Beam Antennas," Paper 29.5, *First Canadian Domestic and International Satellite Communications Conference* (June 1983).
5. *Aviation Week & Space Technology* (19 November 1984), p. 19.

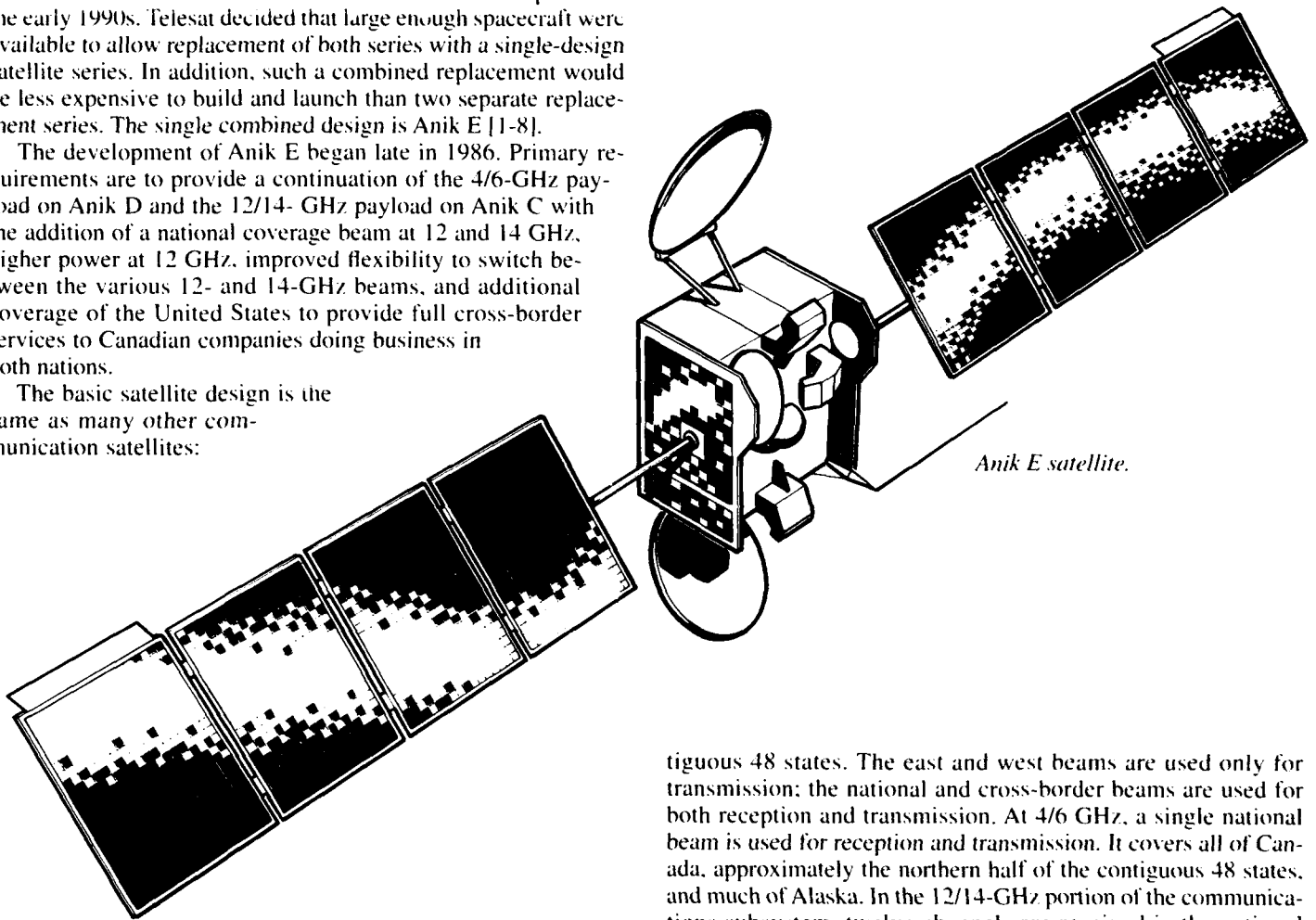
6. *Telecommunication Journal*, Vol. 52, No. 6 (June 1985), p. 385.
7. B. Hanson, A. Smalley, and M. Zuliani, "Implementation of a Light-Route TDMA Communications Satellite System for Advanced Business Networks," Paper 82-0477, *AIAA 9th Communications Satellite Systems Conference* (March 1982).

Anik E

The launch dates and expected lifetimes of the Anik C and D satellites indicated that both series would need to be replaced in the early 1990s. Telesat decided that large enough spacecraft were available to allow replacement of both series with a single-design satellite series. In addition, such a combined replacement would be less expensive to build and launch than two separate replacement series. The single combined design is Anik E [1-8].

The development of Anik E began late in 1986. Primary requirements are to provide a continuation of the 4/6-GHz payload on Anik D and the 12/14-GHz payload on Anik C with the addition of a national coverage beam at 12 and 14 GHz, higher power at 12 GHz, improved flexibility to switch between the various 12- and 14-GHz beams, and additional coverage of the United States to provide full cross-border services to Canadian companies doing business in both nations.

The basic satellite design is the same as many other communication satellites:



Anik E satellite.

a rectangular body with solar panels that deploy in orbit from the north and south faces of the body. Communications equipment is attached to the inside surfaces of the north and south faces; other equipment is mounted in a central cylindrical structure and on panels that join the cylinder to the exterior panels of the satellite body. Two large reflectors deploy from the east and west faces of the body. One is for 4/6 GHz and the other for 12/14 GHz. A third, smaller antenna is fixed on the earth-viewing face of the body. This third antenna is for the 12/14-GHz cross-border beam; the larger 12/14-GHz antenna provides the national, east, and west beams.

At 12/14 GHz, the national beam provides coverage of all of Canada except for some sections of the far north. The east and west beams each correspond to half of the national beam. The cross-border beam covers southern Canada plus most of the con-

tiguous 48 states. The east and west beams are used only for transmission; the national and cross-border beams are used for both reception and transmission. At 4/6 GHz, a single national beam is used for reception and transmission. It covers all of Canada, approximately the northern half of the contiguous 48 states, and much of Alaska. In the 12/14-GHz portion of the communications subsystem, twelve channels are received in the national beam, and four can be individually switched between national and cross-border beams. For transmission, these latter four can be switched to the national, cross-border, or west beam. Two others can be switched between national and east beams. The remaining ten are fixed, four to the west beam and six to the east beam.

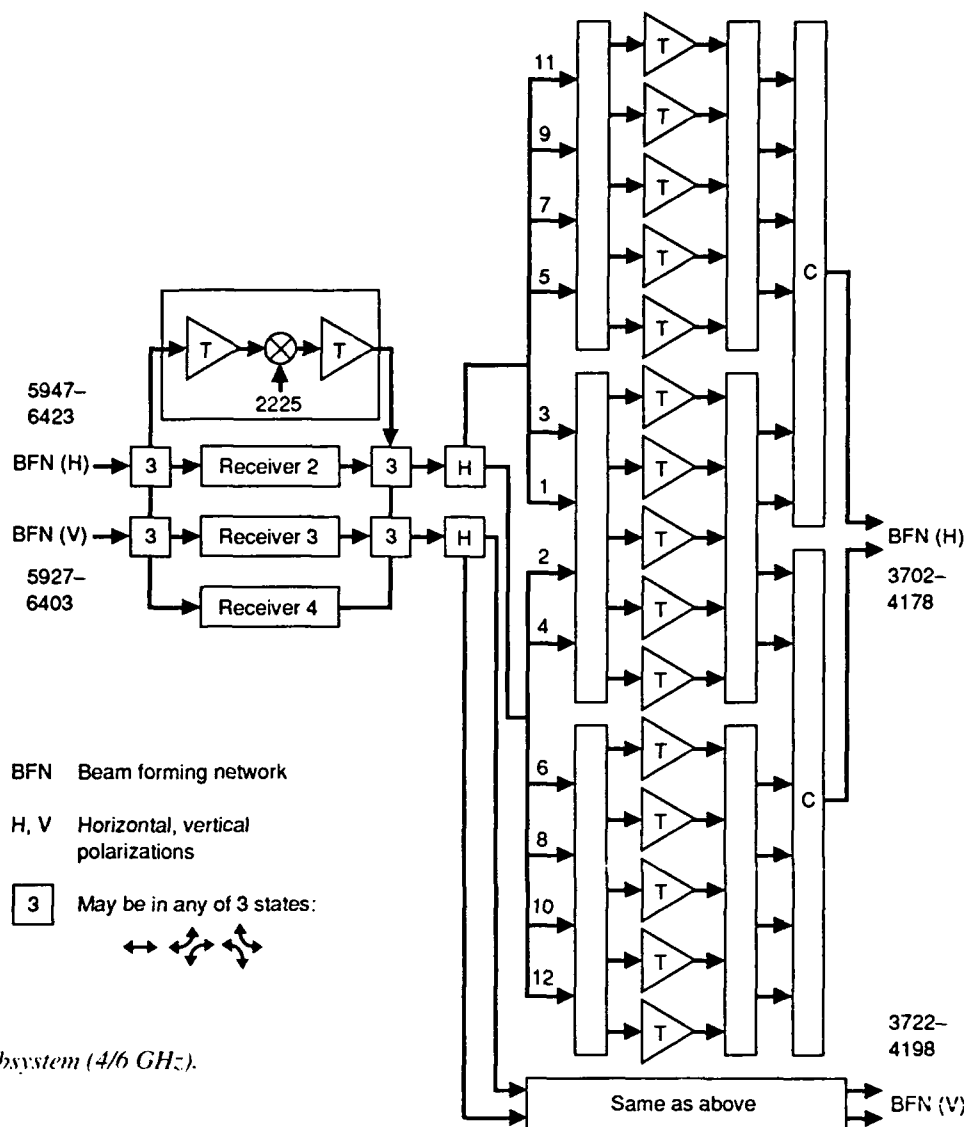
Details of the satellite and communications payload are as follows:

Satellite

Rectangular box body, approximately $6 \times 7 \times 7$ ft, 71-ft span across solar arrays

Approximately 3200 lb in orbit, beginning of life

Sun-tracking solar arrays and NiH_2 batteries, approximately 3900 W after ten years



Anik E communication subsystem (4/6 GHz).

ERP per repeater 45 to 52 dBW in east and west beams, 45 to 49 dBW in national beam, 43 to 45 dBW in cross-border beam

Receiver

4/6 GHz: 5927 to 6423 MHz

Two active receivers plus two spares

G/T -3 dB/K over all of Canada

12/14 GHz: 14.003 to 14.497 GHz

Three active receivers plus two spares

G/T 1.5 to 2.5 dB/K over Canada

Antenna

4/6 GHz: one 82-in.-dia. offset-fed dual-grid parabola with multiple feedhorns, dual linear polarizations

12/14 GHz: two offset-fed dual-grid parabolas; one 82-in.-dia. with multiple feed horns for national, east, and west beams, dual linear polarizations; one 40-in.-dia. with multiple feed horns for cross-border beams, single polarization

Design life

(Twelve years fuel load)

Orbit

Synchronous equatorial, stationkeeping to $\pm 0.01^\circ$ N-S and E-W

Orbital history

1: launched 26 September 1991, 111° W longitude

2: launched 4 April 1991, in use, 107.3° W longitude

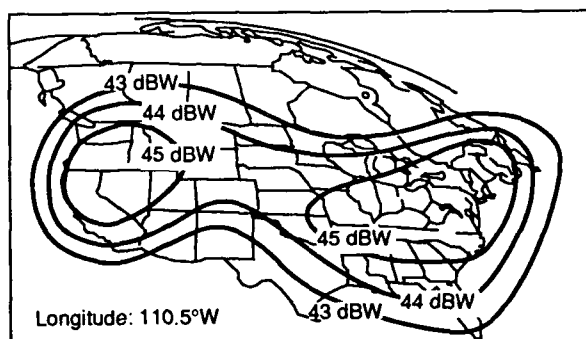
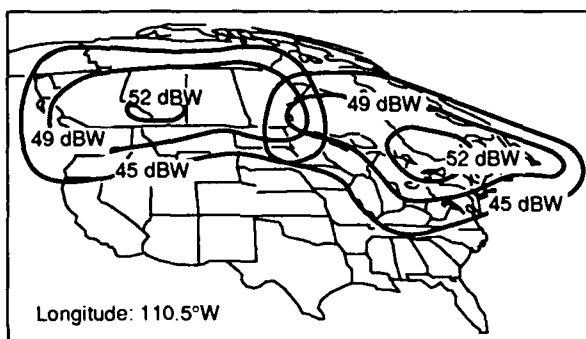
Ariane launch vehicle

Management

Developed for Telesat Canada by Spar Aerospace with GE Astro-Space as a major subcontractor

Operated by Telesat Canada

The Anik E development program is a protoflight approach, where the first flight satellite will qualify the design. Distinct qualification models were built only for the solid-state amplifiers, antennas, some propulsion components, and batteries. The first satellite was launched in April 1991. The 12/14-GHz antenna was deployed only after anomalous behavior, and the 4/6-GHz antenna could not be deployed. Since the latter antenna was blocking the attitude control sensors, the whole satellite was disabled. The antenna was finally deployed, three months after launch, by



Anik E antenna patterns.

spinning the satellite. The second satellite was launched 26 September 1991 and will be put into orbital storage unless problems occur with the first satellite. The storage will use a slightly inclined orbit chosen so that zero inclination will be reached, without use of stationkeeping fuel, in a few years. At that time, the satellite will be activated.

* * * * *

1. E. Bertenyi and R. Tinley, "Telesat Canada's Anik E Spacecraft," *Acta Astronautica*, Vol. 16 (1987).
2. A. Shoamanesh and R. Taylor, "Telesat Canada's Anik E Communications Satellite System," Paper 88-0783, *AIAA 12th International Communication Satellite Systems Conference* (March 1988).
3. R. C. Whitehouse, "The Anik E Antenna Farm," *IEEE International Symposium on Antennas and Propagation* (June 1989).
4. A. Kidd and E. Bertenyi, "Anik E Spacecraft Development and Test," Paper 90-0825, *AIAA 13th International Communication Satellite Systems Conference* (March 1990).
5. *Aviation Week & Space Technology* (8 December 1986), p. 85; (20 April 1987), p. 20; (9 September 1991), p. 76.
6. *Satellite Communications* (February 1988), p. 27; (May 1989), p. 19; (February 1991), p. 25.
7. R. deCamprieux, M. Zuliani, and D. E. Weese, "Anik E: Meeting User Requirements in the 1990's," *The Canadian Satellite User Conference* (May 1987).
8. L. A. Keyes and H. J. Moody, "Evolution of the Anik E Payload," *The Canadian Satellite User Conference* (May 1987).

Telesat System

The Telesat system [1-17] handles a wide variety of traffic, reflecting the diverse needs of the country. Television distribution is a major function of the system. Transmissions are FM with one video plus several audio signals per satellite repeater, except for Anik C (two per repeater). Telephony is another major function. FDMA has been in use since the beginning, with FDM voice channels on high-density routes and QPSK/SCPC on low-density routes. Voice activation is used on the SCPC links to conserve satellite capacity. On Anik C, all voice channels are transmitted digitally. The use of TDMA started in the late 1970s and has increased, but it is not yet as common as FDMA. Data transmission also exists in the system at rates from 2.4 kbps to 6.1 Mbps.

The Telesat system includes many types of ground terminals for communications plus three telemetry, tracking, and command (TT&C) terminals. The characteristics of these terminals are given in Table 1. The original terminals all operated in the 4- and 6-GHz bands. The heavy-route terminals, with 97-ft antennas, are equipped for all communications services, and each has several transmitters and receivers for handling multiple simultaneous links. In addition, these terminals have a complete set of TT&C equipment. The network TV terminals are primarily for transmission and reception of high-quality TV. Northern telecommunications terminals provide voice links with the heavy-route stations and reception of television for local rebroadcasting to home receivers. Remote TV terminals receive television transmissions for local rebroadcast, and they have the capability of being expanded to provide two-way telephone service. This capability has

been used in several terminals subsequent to their initial installation. The thin-route terminals provide limited two-way telephone service and can be upgraded to add television reception capability.

Initially, early in 1973, the system had 36 communication terminals. The number grew to 100 in a few years, then gradually increased to about 150. Most terminals are the remote television and thin-route types. Over half of these new terminals are located in the northern territories of Canada. Because of the large number of terminals in remote locations, considerable effort was made to keep them inexpensive. Thus, only the heavy-route and TT&C terminals require full-time manning. Also, since the satellites have stationkeeping to ± 0.1 deg or better, only these two types of terminals require automatic tracking.

Satellite and network control for the Telesat system is accomplished from a control center near Ottawa. Satellite control is accomplished primarily using the heavy-route terminal near Toronto and the collocated TT&C terminals. The heavy-route terminal is pointed at the primary satellite, and a TT&C terminal is pointed at each of the other satellites.

The Anik C system became operational in 1983, using the 12- and 14-GHz bands, with ten main terminals in the major cities. These terminals have 25-ft antennas, with automatic step tracking. Six are equipped for telephone and television transmission and reception, and four for television only. For augmenting the major routes of the Trans-Canada Telephone System, data rates up to 90 Mbps can be transmitted. Additional 15-ft antennas will

Table 1. Canadian Ground Terminals

TERMINAL TYPE ^a	ANTENNA DIAMETER, ft	G/T, dB/K	TRANSMITTERS INSTALLED/STATION	ERP/CHANNEL, dBW	RECEIVERS INSTALLED/STATION	ANTENNA STEERING	NO-BREAK STANDBY POWER
HR	97	37	3-8	83	5-10	Step track	Batteries and diesel
NTV	33	28	1-3	83	4	Manual	Batteries and diesel
NTC	33	28	2	73	2-3	Manual	Batteries and diesel
RTV	26	26	0 ^b	0 ^b	1-2	Manual	Batteries
TR	26	26	2	58	2	Manual	Some have batteries
FTV	12-15	20-22	0	0	1	Manual	Some have batteries
Transportable	12-28	< 26	0-2	~54	1-2	Manual	Some have batteries
TT&C	15-36	17-28	2	85	2	Monopulse or manual	Batteries and diesel
HR(12/14)	26	35	2-8	~85	≥ 2	Step track	Batteries and diesel
MR(12/14)	15	28.5	1-2	~85	2		
TV(12/14)	25	33	2-3		22	Step track	Batteries and diesel
TT&C (12/14)	15/36	26/35	2	81/91	2	Manual/monopulse	Batteries and diesel

^aTerminal type

4/6 GHz:

HR Heavy route
 NTV Network television
 NTC Northern telecommunications (or medium route)
 RTV Remote television
 TR Thin route
 FTV Frontier television
 TT&C Tracking, telemetry, and command

12/14 GHz:

HR Heavy route
 MR Medium route
 TV TV distribution
 TT&C Tracking, telemetry, and command

^bSome RTV terminals have had a TR capability retrofitted

be installed as needed for television transmission and reception or for reception only, or for transmission and reception of 45-Mbps digital data streams. In another type of use, after Anik C2 was launched, its antenna was tilted 0.5 deg south from normal Canadian coverage, for temporary use on lease to a United States company as a medium-power broadcasting satellite. Business communications, both voice and data, are a new service developing on Anik C. Various data rates are available. Transmissions are QPSK/TDMA, with burst rates of 30 Mbps or higher.

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UNITED STATES (Domestic Communications)

The satellite systems described here are, or will be, providing domestic communication services for the United States. Together, these systems serve the continental United States (CONUS), Alaska, Hawaii, Puerto Rico, and the Virgin Islands [1-18].

In September 1965, the American Broadcasting Company filed a request with the Federal Communications Commission (FCC) for authorization to operate a communication satellite system for distribution of network television. This application was returned by the FCC without comment, pending an inquiry concerning public policy questions related to the establishment of domestic communication satellite systems. This inquiry began in March 1966, with many diverse organizations presenting their views to the FCC. During the next few years, many studies, opinions, system proposals, and experimental plans were submitted. In addition to the FCC inquiry, both the legislative and executive branches of the government studied domestic satellite systems. In 1968, a task force appointed by the President prepared a report favoring a limited pilot program. However, just at the time the report was published, a new administration was elected and a new investigation was started. In January 1970, the study group issued a report favoring open entry for domestic satellite systems. On the basis of this report, the FCC in March 1970 invited applications for permission to construct and operate the systems. By the March 1971 deadline, eight applications were filed.

FCC action on these applications was prolonged by more comments, claims, and counterclaims. A tentative decision in June 1972 modified the open entry policy to require each applicant to show financial and technical qualifications and that the proposed service would be in the public interest. This decision also placed specific restrictions on certain applicants. Following further arguments, a final FCC decision in December 1972 opened the way for processing of the applications. The FCC had allowed opportunities (after the March 1971 filing) for applicants to drop, modify, or combine applications. As a result, there were five active applications at the start of 1973: Western Union Telegraph Company, American Satellite Corporation, Hughes Aircraft Company with GTE Satellite Corporation, Comsat General Corporation with AT&T, and RCA Globecom with RCA Alascom.

Three approvals were required for each system, covering the satellite equipment, ground equipment, and system operations. By January 1974, all five applicants had received one or more of these approvals, and both satellite and ground equipment were being built. However, in February 1974, American Satellite Corporation cancelled its order for three satellites because of lack of financing. Then, in April of the same year, AT&T and GTE an-

nounced plans to combine their systems using the satellites being developed for AT&T. At the end of 1974, the status of these applications was as follows:

- Western Union Telegraph Company began operations in 1974.
- RCA was developing its own satellites. (Initial operations began in December 1973 with satellite capacity leased from Telesat Canada.)
- AT&T was proceeding toward operational status, with Comsat General developing satellites for the system.
- GTE had dropped plans for its own system, preferring joint operations with AT&T; the next year it became a user of the AT&T system, rather than a joint owner.
- American Satellite Corporation was leasing satellite capacity from Western Union.

The RCA and AT&T systems began operations in 1976. By the fall of that year, each had two satellites in orbit, as did Western Union. Prior to the development of these systems, the Intelsat system was used for satellite communications between CONUS and Hawaii, Alaska, and Puerto Rico. The Intelsat terminal in Alaska became a part of the RCA system, and the terminal in Puerto Rico became a part of the AT&T system. Although these systems serve Hawaii, the Intelsat terminal there has remained in the Intelsat system to link Hawaii with many Pacific nations and islands. In the same year, CML Satellite Corporation, a combination of two of the eight March 1971 applicants, reorganized as Satellite Business Systems (SBS). FCC approval was received in 1977, and the first SBS satellite was launched late in 1980. The system became operational in March 1981. At the end of 1980, nine satellites were in orbit: three each for the Western Union and AT&T systems, two for RCA, and one for SBS. In addition, a third RCA satellite was destroyed just before reaching the synchronous orbit.

During the first few years after Western Union and RCA started operations, the demand for satellite capacity was quite low. In about 1978, the demand started to increase very quickly. By early 1980, the FCC had several applications to consider, some for expansion of existing systems and some for new systems. Those that were filed before 1 May of that year were considered together and approved in December. New systems that were authorized are Hughes Communications, Inc. (HCI), Southern Pacific Communications Company (SPCC), and GTE Satellite Corporation (GSat). In 1983, GTE purchased SPCC, and the latter two systems were combined under the name GTE Spacenet.

In 1981, the FCC started a broad review of the domestic satellite licensing policy. The objective of this review was to formulate the best method of allocating orbital and spectral resources to what was foreseen as an ever increasing demand. The primary emphasis was on the orbital spacing of satellites. In 1970, 5-deg spacing between satellites was assumed necessary to prevent interference. In 1974 this was reduced to 4 deg. In the 1980 decisions, 4 deg was used for satellites that were using the 4/6-GHz bands and 3 deg for those using the 12/14-GHz bands.

The review started in 1981 was not completed until April 1983. At that time, the orbital spacing was reduced to 2 deg for both frequency bands; implementation of this spacing was to proceed over the next few years. This action almost doubled the number of potential satellite locations in orbit. However, most of these locations were assigned to new satellites and new systems authorized in concluding the review. The 1983 authorizations, covering all applications received by May 1982, included additional satellites for several systems plus five new systems: RCA, for use of the 12/14-GHz bands in addition to the 4/6-GHz satellites, American Satellite Corporation, United States Satellite Systems, Rainbow Satellite, and Advanced Business Communications. American Satellite was well established in the business; it had operated an increasing number of ground terminals with the Westar satellites since 1974. The latter three companies received provisional authorizations and were required to submit evidence of their financial ability to develop the systems. Since none of them was able to present satisfactory evidence, all three authorizations were revoked early in 1985, in order to clear

the way for the FCC to proceed with the next set of authorizations.

By the time of the 1983 authorizations, several other applications were submitted to the FCC. Additional applications arrived in the following months. Again, the FCC conducted a broad review of domestic satellite policy prior to studying the individual applications. Topics of particular interest were the number of orbital positions (often called slots) available, the efficiency with which each is used, and the financial qualifications of applicants.

To some extent, the number of slots was fixed by the previous 2-deg spacing decision. However, there were still contentions about how fast to transition the 4/6-GHz satellites to the new spacing. The contention focused on the many existing ground antennas, which were not compatible with 2-deg spacing, and the cost to improve them, or to replace them before they would otherwise be replaced. Another consideration regarding the number of slots was the potential utility of some slots farther east or west than those presently assigned. To provide for efficient use of each slot, the FCC required all satellites to use dual-polarization frequency reuse, which was already used on most satellites. The FCC also developed minimum standards for numbers of transponders, their bandwidths, and TWT power for 12/14-GHz satellites. These characteristics had become relatively fixed on 4/6-GHz satellites, but varied among the higher-frequency satellites. Finally, the FCC stated more specific measures for applicants' financial qualifications.

By early 1985, applications from about 20 organizations were pending. A decision was announced in the summer of 1985. Six

Table 1. Domestic communication satellites

ORGANIZATION ^a	SATELLITE NAME	FREQUENCY BAND ^b	NOTES						
			c	d	e	f	g	h	
Western Union	Westar	C	1973	2	3	4	4	5	
		K	1985					2	
RCA	Satcom	C	1973	2	2	4	4	6	
		K	1983				2	3	
AT&T	Comstar, Telstar	C	1973	2	3	4	4	4	
SBS	SBS	K	1977		1	3	4	6	
Hughes Communications, Inc. (HCI)	Galaxy	C	1980			2	3	4	
		K	1985					2	
GTE Spacenet	Spacenet	C-K	1980				2	3	
GTE Spacenet	GStar	K	1980				2	2	
American Satellite Corp. (ASC)		C-K	1983				1	3	
Alascom, Inc.	Aurora	C	1985			1*	1*	2	
Comsat General Corp.		K	1985					2	
Federal Express Corp.	Expresstar	K	1985					2	
Ford Aerospace Satellite Services Corp.	Fordsat	C-K	1985					2	
Martin Marietta Communication Systems, Inc.		K	1985					2	
Total				6	9	18	27	51	

^a Does not include organizations who canceled plans for authorized systems or had authorizations revoked.

^b C = 4/6 GHz, K = 12/14 GHz, C-K = both C and K on the same satellite.

^c Year system first authorized (additional satellites and other major changes require additional authorization).

^d Number of useable satellites in orbit December 1976.

^e Number of useable satellites in orbit December 1980.

^f Number of useable satellites in orbit December 1983.

^g Number of useable satellites in orbit March 1986.

^h Number of orbital positions authorized at the conclusion of the 1985 FCC proceedings. Number of satellites authorized is larger because it includes spares to be kept on the ground.

ⁱ Includes new satellites owned by AT&T and older satellites owned by Comsat General and leased to AT&T.

^j GTE Spacenet has one additional authorization for either type of satellite.

^k An RCA satellite sold to Alascom.

previously authorized systems were each granted one additional orbital slot. Western Union and HCI, which already were operating 4/6-GHz satellites, were authorized to use the 12/14-GHz band also. Five new systems were authorized: Alascom, Inc.; Comsat General Corporation; Federal Express Corporation; Ford Aerospace Satellite Services Corporation; and Martin Marietta Communication Systems, Inc. Alascom was formerly an RCA subsidiary and already had one satellite in use that it bought from RCA. Comsat General had developed four satellites in the 1970s in a lease agreement with AT&T. This authorization was for a new, unrelated system. Five other applications were rejected as financially unqualified, and two applicants withdrew before the FCC proceedings were concluded.

Another round of applications had gathered by September 1987. Six previously authorized companies requested additional satellites, and one new company (National Exchange) requested authorization to operate a system. In 1988, the FCC allowed further applications, but only for replacement satellites. The deadline for these was October. The issues the FCC faced in 1988 and 1989 were satellite spacing, how to accommodate ever higher 12-GHz transmitter powers without interference to adjacent satellites, and whether to require some in-orbit satellites to move in order to accommodate newly authorized satellites. The FCC decision was announced in November 1989. A total of ten replacement satellites were authorized, along with thirteen new satellites of which four are ground spares.

However, along with the increase in applications and authorizations through the 1980s, business practicality led to a decrease in the number of operational systems. The first step was the consolidation of the GTE and Spacenet systems in mid-decade. HCI absorbed Western Union satellites later in the decade. Four applicants authorized in 1985 did not carry through with their plans: Comsat General, Federal Express, Ford Aerospace, and Martin Marietta. The decade of the 1990s began with HCI buying the three SBS satellites that had significant remaining life.

As a result, by the end of 1990 only six companies had domestic communications systems with their own satellites:

- Alascom
- AT&T
- Contel ASC
- General Electric
- GTE Spacenet
- Hughes Communications, Inc.

Even among these six, the Alascom system is dependent on, and to some extent a part of, the GE system. Furthermore, Contel and GTE merged in March 1991, thereby reducing the number of independent systems to four. Each system except AT&T has at least four satellites operating in orbit. HCI and GE along with Alascom are predominately using 4/6 GHz, although GE has, and HCI is building, satellites for 12/14 GHz. In contrast, GTE and Contel are primarily a 12/14 GHz system, although some of the satellites have 4/6-GHz subsystems.

The market for domestic satellite services is strong enough to allow these four systems to continue in a healthy condition. However, prospects for new systems, include that of National Exchange which was authorized in 1989, are poor. The reasons are the large financial investment required to build and launch satellites, and the fact that the major customers tend to have long-term contracts with existing systems.

Along with the satellite population growth has been an even faster growth in earth terminals. In the mid 1970s, the number of

terminals per satellite was a few dozen. Each had an antenna at least 30 ft in diameter and considerable electronics. In the late 1970s, the distribution of television, especially to cable television systems, started and grew quickly. By 1980, the number of terminals was probably about 1000, most with antenna diameters less than 40 ft, many only capable of receiving television. This type of terminal has increased in number to about 10,000, with the typical antenna diameter now about 20 ft or less. In the 1980s, as the result of the dozens of television programs available on communication satellites, the market for television receive terminals for homes boomed. These terminals, which typically have 8- to 15-ft antennas and cost about \$1000 to \$3000 each, were estimated to number 600,000 in 1985 and extended to one million by 1990. Meanwhile, although the number of large terminals with multiple transmit and receive capabilities has increased, they still probably number no more than one or two thousand. Another type of terminal having considerable growth since the mid-1980s is the very small aperture terminal (VSAT). The typical antenna diameter is 4 to 6 ft. These are used primarily for data networks, where many remote locations are tied to a hub with a larger terminal. Data transmission may be one way to the hub, or one way from the hub, or bidirectional between the hub and the VSATs. The total number of VSATs in use probably exceeds 100,000.

* * * * *

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Western Union

The first set of Western Union satellites [1-25] were Westar I, II, and III. They were nearly identical to the Canadian Anik A satellites. The satellite was spin-stabilized; the body and all equipment within it spun, only the antenna was despun. The antenna was 5 ft in diameter and was fed by an array of three horns that produced a pattern optimized for CONUS. A fourth horn provided a lower-level beam for Hawaii. The communication subsystem had twelve channels with a bandwidth of 36 MHz each. Each channel had a single TWT. The satellite had no spare TWTs, but it was expected that ten of the twelve channels would be operable at the end of the satellite's seven-year life, which was true for both Westar I and II in 1981. Details of the Westar I through III satellites are as follows:

Satellite

Cylinder, 75-in. dia., 67-in. height (139 in. overall)

655 lb in orbit, beginning of life

Solar cells and NiCd batteries, 305 W at beginning of life, 260 W minimum after seven years

Spin-stabilized, 100 rpm, ± 0.1 -deg accuracy

Solid rocket motor for apogee maneuver, liquid monopropellant for on-orbit use

Configuration

Twelve 36-MHz bandwidth single-conversion repeaters

Capacity

Up to 1200 one-way voice circuits or one TV program per repeater

Transmitter

3702 to 4178 MHz

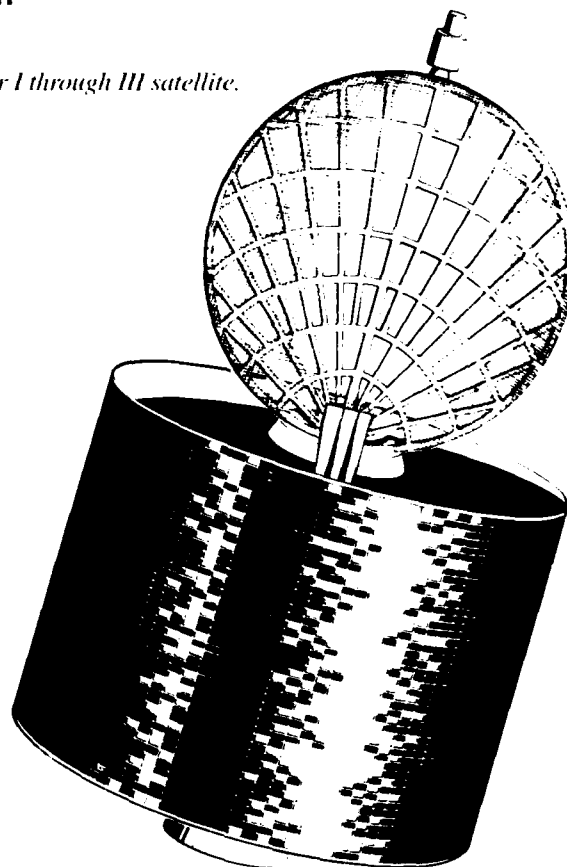
One 5-W TWT per repeater (no TWT redundancy)

ERP per repeater at edge of coverage: 34 dBW (CONUS), 24 dBW (Puerto Rico), 27 dBW (Alaska, Hawaii)

Receiver

5927 to 6403 MHz

Westar I through III satellite.



Two receivers (one on, one standby), 8-dB noise figure
G/T at edge of coverage: -7 dB/K (CONUS), -8 dB/K (Alaska),
-13 dB/K (Hawaii), -17 dB/K (Puerto Rico)

Antenna

One 60-in.-dia. reflector with three feed horns combined for coverage of CONUS and Puerto Rico, separate feed horns for Alaska and Hawaii, linear polarization

Design life

Seven years

Orbit

Synchronous equatorial, stationkeeping to $\pm 0.1^\circ$ N-S and E-W

Orbital history

I: launched 13 April 1974, turned off April 1983, moved out of synchronous orbit

II: launched 10 October 1974, service life about ten years, then moved above synchronous orbit

III: launched 10 August 1979, in use until January 1990, turned off, moved above synchronous orbit

Delta 2914 launch vehicle

Management

Developed by Hughes Aircraft Company for Western Union

Operated by Western Union

The first Westar was launched in April 1974 and the second in October 1974. Regular service started in July 1974 with five Western Union terminals in major urban areas of CONUS. Westar III was launched in August 1979. Westar I was removed from service in April 1983, Westar II the next year. Westar III was included in the Westar satellites sold to Hughes Communications in 1988. It was turned off in 1990.

Advanced Westar, proposed as the second-generation space segment, and the NASA TDRSS space segment are integrated into a common satellite design. The basic design is described in the TDRSS discussion. The satellite has three communication

subsystems: S-band for TDRSS, C-band for Advanced Westar, and K-band for either system. However, conflicts developed that resulted in the termination of the joint Western Union and NASA use of the satellites. The satellites are used only by NASA, even though they still have the Advanced Westar equipment.

In 1980, Western Union ordered a Westar IV satellite, primarily to ensure that there was no gap before Advanced Westar was available. Westars V and VI were added within a year. With the end of Advanced Westar, the company applied for permission to build Westars VII and VIII. Westar VIII was not built. Westar VII was renamed Westar VI-S after the Westar VI problem (see below); later it was sold, prior to launch, to Hughes Communications and became Galaxy VI. The details of the Westar IV through VI satellites are as follows:

Satellite

Cylinder, 85-in. dia., 269-in. height (22.4 ft) in deployed condition

1285 lb (IV, V)/1340 lb (VI) in orbit, beginning of life

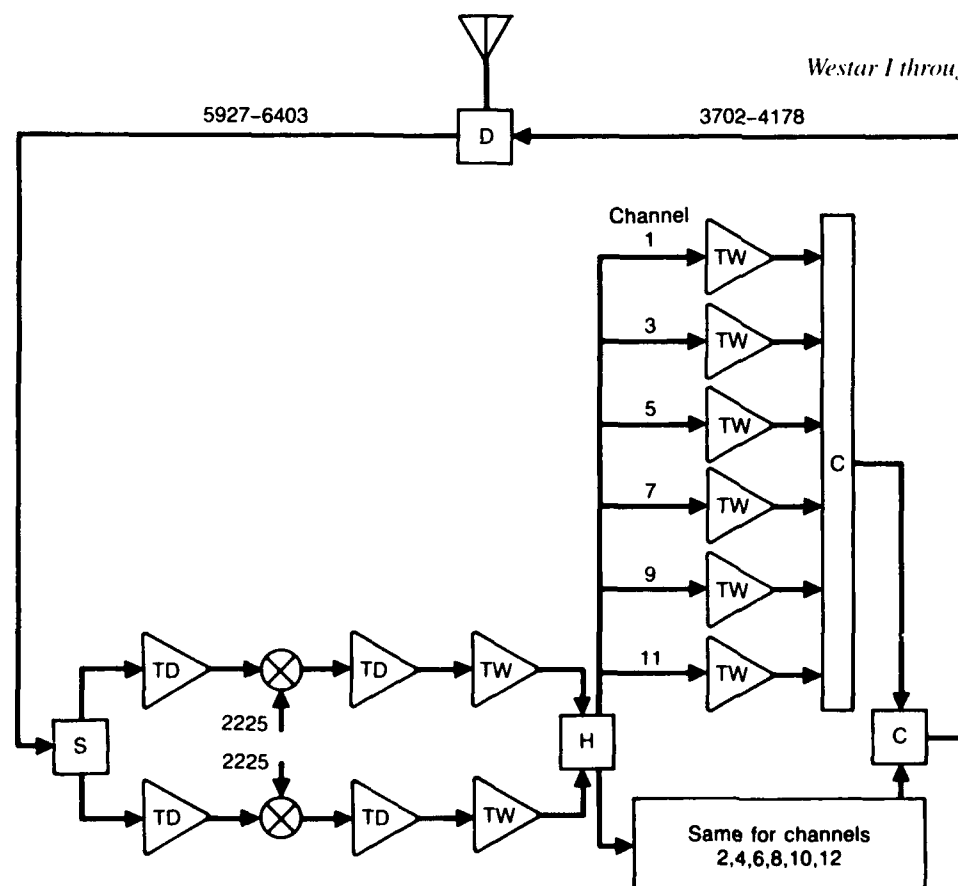
Solar cells and NiCd batteries, 840 W at beginning of life, 694 W at end of life

Spin-stabilized, gyrostat, approximately 60 rpm

Solid rocket motor for apogee maneuver, liquid monopropellant propulsion for on-orbit use

Configuration

Twenty-four 36-MHz bandwidth single-conversion repeaters, dual-polarization frequency reuse



Westar I through III communication subsystem.

Capacity

Up to 1200 one-way voice circuits or 64 Mbps or one TV program per repeater

Transmitter

3702 to 4198 MHz

One TWT per repeater plus six spares per satellite; 7.5 W (IV, V)/8.2 W (VI) per TWT

ERP per repeater at edge of coverage: 34 dBW (IV, V)/34.5 dBW (VI) (CONUS); 32.2 dBW (IV, V)/30 dBW (VI) (Alaska); 30 dBW (IV, V)/29.1 dBW (VI) (Hawaii); 27.1 dBW (IV, V)/27.9 dBW (VI) (Puerto Rico)

Receiver

5927 to 6423 MHz

Two active plus two spare receivers

G/T at edge of coverage: -6 (IV, V)/-4 (VI) dB/K (CONUS), -7 (IV, V)/-6 (VI) dB/K (Alaska), -7 (IV, V)/-9 (VI) dB/K (Hawaii), -7 (IV, V)/-6 (VI) dB/K (Puerto Rico)

Antenna

Two 72-in.-dia. paraboloids with polarizing grids, one behind the other; primary beam shaped to cover CONUS, Alaska, and Puerto Rico; secondary beam to cover Hawaii; orthogonal linear polarizations

Design life

Ten years

Orbit

Synchronous equatorial, stationkeeping to $\pm 0.1^\circ$ N-S and E-W

Orbital history

IV: launched 26 February 1982, 99° W longitude, in use

V: launched 9 June 1982, 122° W longitude, in use

VI: launched 3 February 1984 (deployed from Shuttle, 3 February). PAM failure left satellite in low orbit, recovered and returned to earth November 1984

Delta 3910/PAM launch vehicle (IV, V), Shuttle/PAM launch vehicle (VI)

Management

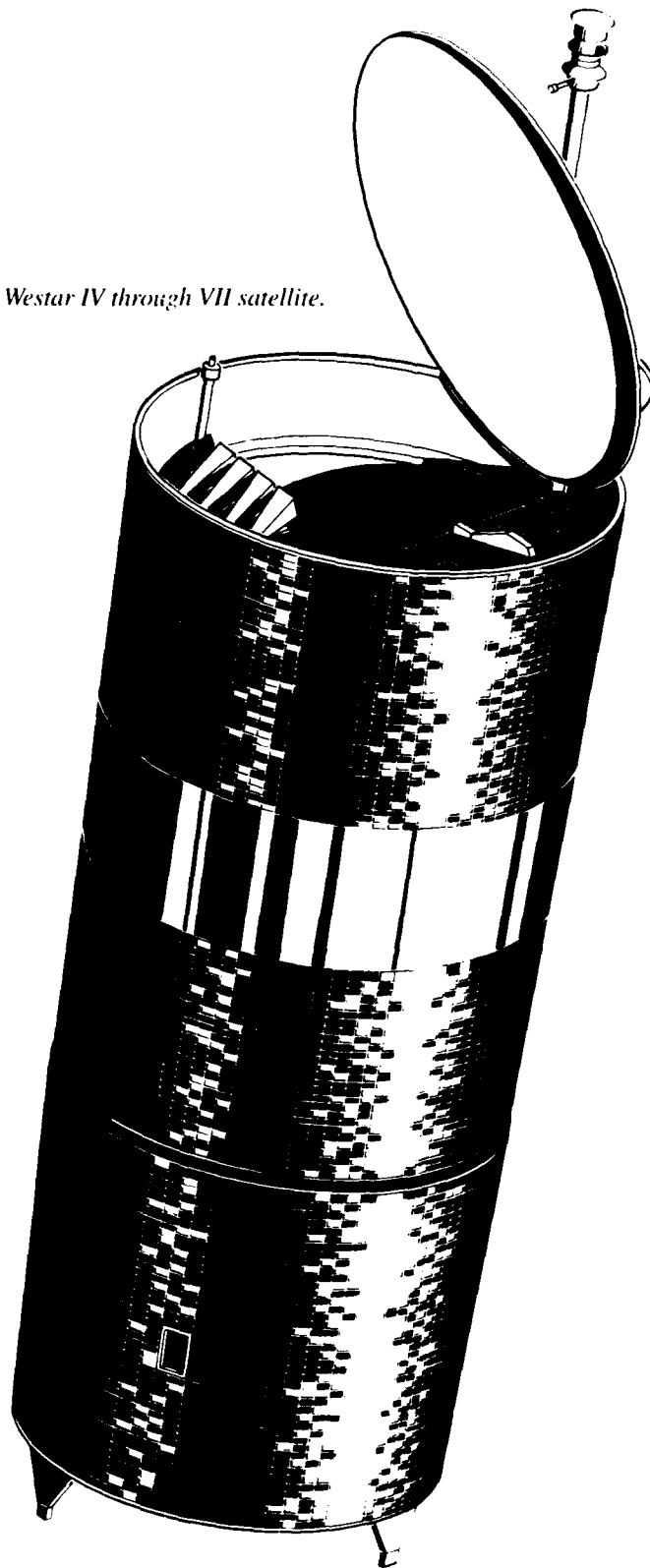
Developed by Hughes Aircraft Company for Western Union

Operated by Western Union

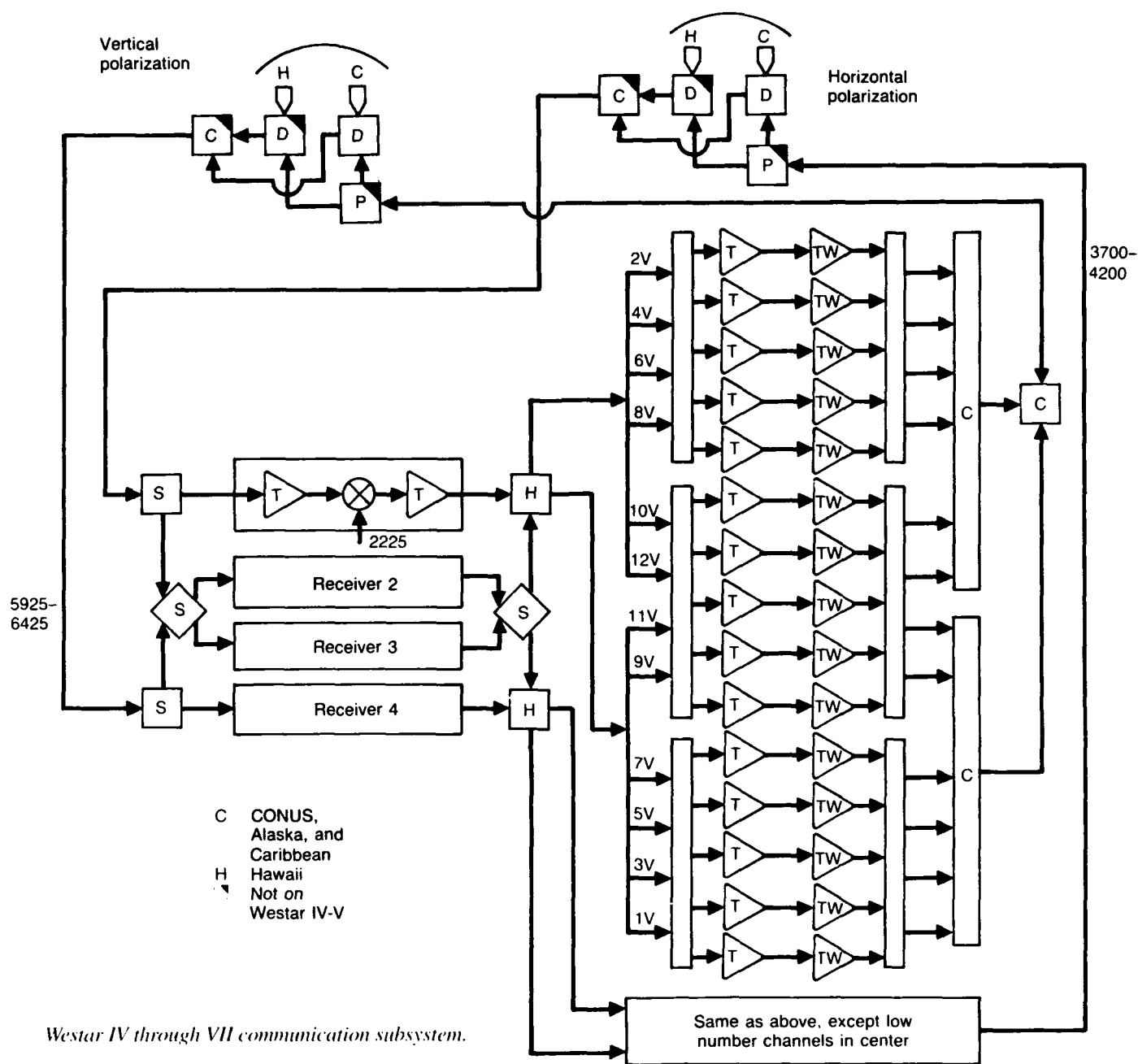
Westars IV through VI are larger and have more capacity than the earlier satellites. Except for communication subsystem details, the satellites are the same as the SBS satellites. They have a cylindrical body that is covered with solar cells except for a band that is a thermal radiator. Additional power is generated by a cylindrical array that surrounds the main body during launch and is deployed in orbit. The antenna, which is deployed in orbit, and the communications equipment are mounted on a platform that is despun during satellite operations.

The communication subsystem has 24 channels and transmits and receives 12 on each of two orthogonal linear polarizations. Signals received on one polarization are transmitted on the opposite one. The dual-polarized main beam covers CONUS, Alaska, and the Caribbean, with lesser gain for the latter two. A secondary beam covers Hawaii with only one polarization in Satellites IV and V, but both in Satellite VI. Internally, the subsystem is typical of many other satellites with broadband receivers and individual TWTs for each channel.

Westar IV through VII satellite.



Westars IV and V were launched in 1982 and are in use. Westar VI was launched in February 1984 but was left in a low orbit because of a perigee motor failure. A rescue plan [24] was devised that involved numerous adjustments to the satellite orbit, while adapters were designed and built to hold the satellite in the Shuttle. A Shuttle mission in November 1984 rendezvoused with the satellite. Two astronauts, working outside the Shuttle, captured the satellite and secured it in the Shuttle bay. The satellite



was returned to earth and was refurbished and offered for sale. It became Asiasat, which is described in an earlier section (International Satellites). Westar VII became Westar VI-S and was part of the 1988 sale of all Westar satellites to Hughes Communications. Westar VI-S had not been launched at the time of the sale; with minor modifications it became Galaxy VI.

Westar IX through XI were planned Ku-band (12- and 14 GHz) satellites. They were authorized by the FCC but never built.

Prior to the sale to Hughes Communications, Westar satellites were operated from a control center at a Western Union ground terminal in New Jersey. Western Union had ground terminals near six other major urban areas. These were sold separately from the satellites. They were used for transmission of telephone and message traffic. Several other companies had their own ground termi-

nals that they used with the Westars for telephone, data, and video conferencing. The biggest use of Westar satellites was for distribution of television programs. The Public Broadcasting System used Westar to distribute four programs to almost 200 ground terminals associated with its member stations. Numerous companies used Westar to distribute regular programming or occasional events to cable television systems. Other uses of Westar included transmission of facsimile pages of *The Wall Street Journal* to more than a dozen printing plants around the nation. Many of these transmissions continued uninterrupted when the Westars became part of the Hughes Communications Network. Transmission techniques used on Westar satellites include FDM/FM, TDMA at burst rates up to 62 Mbps, TV/FM, and low rate data with spread spectrum coding.

* * * * *

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AT&T (Comstar, Telstar 3, Telstar 4)

The AT&T system [1-17] started operating in 1976 using the Comstar satellites. They were a derivative of Intelsat IV. The two satellites were the same size, and the structure and support subsystems were very similar. Like Intelsat IV, Comstar was a dual-spin type satellite. Externally, the body was a cylinder covered with solar cells. Internally, most support equipment was attached to the spinning structure. The communication subsystem and antennas were mounted on a despun shelf, which was oriented to keep the antennas earth pointing. Although the solar array was the same size as that of Intelsat IV, the end-of-life power was greater on Comstar due to the use of newer, higher efficiency solar cells. The satellite details are as follows:

Satellite

Cylinder, 94-in. dia., 111-in. height (239 in. overall)
1787 lb in orbit, beginning of life

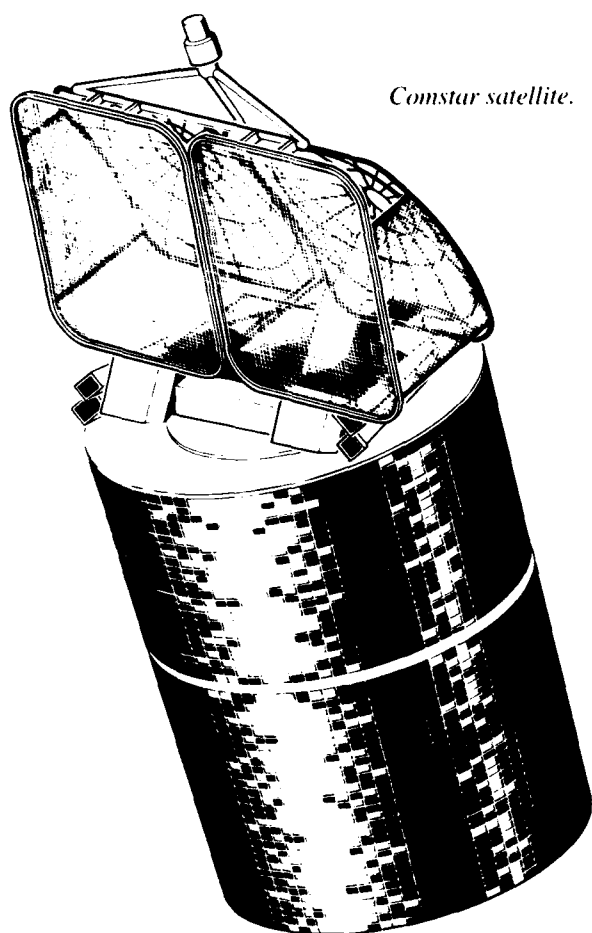
Solar cells and NiCd batteries, 760 W maximum at beginning of life, approximately 550 W minimum at end of life
Spin-stabilized, gyrostabilized, approximately 55 rpm, maximum antenna pointing error $\pm 0.26^\circ$ N-S, $\pm 0.2^\circ$ E-W
Solid rocket motor for apogee maneuver, liquid monopropellant for on-orbit use

Configuration

Twenty-four 34-MHz bandwidth single-conversion repeaters, dual-polarization frequency reuse

Capacity

Up to 1200 one-way voice circuits or one TV program or 45 Mbps per repeater, specified, actual use ≥ 1500 one-way voice circuits plus 1.5 Mbps data



Comstar satellite.

Transmitter

3700 to 4200 MHz

One 5-W TWT per repeater (horizontal polarization transmission), one 5.5-W TWT per repeater (vertical polarization transmission), no redundancy

ERP per repeater at edge of coverage: 33 dBW (CONUS, Hawaii, Alaska, Puerto Rico), 31 dBW (combined CONUS and Alaska coverage), specified: 36 dBW typical, 34 dBW minimum achieved over CONUS

Receiver

5925 to 6425 MHz

Four receivers (two on, two standby)

G/T: -8.8 dB/K (specification), -4.5 dB/K (typical)

Antenna

Two antennas 50 × 70 in. (one for horizontal polarization transmission and reception with six feed horns to provide CONUS, Hawaii, and Puerto Rico coverage; one for vertical polarization with five feed horns for CONUS and Alaska coverage); 24.5-dB receive gain, 26.5/27-dB transmit gain (vertical/ horizontal); CONUS beam approximately 3.5 × 7 deg; 33-dB isolation between the two polarizations

Design life

Seven years

Orbit

Synchronous equatorial, stationkeeping during regular lifetime to $\pm 0.1^\circ$ N-S and E-W

Orbital history

1: launched 13 May 1976, moved above synchronous orbit 1987 or 1988

2: launched 22 July 1976, 76°W longitude, spare, 6-deg inclination in 1991

3: launched 29 June 1978, turned off 1984, moved above synchronous orbit

4: launched 21 February 1981, 76°W longitude, spare, 5-deg inclination in 1991

Atlas-Centaur launch vehicle

Management

Developed by Hughes Aircraft Company for Comsat General Corporation (for lease to AT&T)

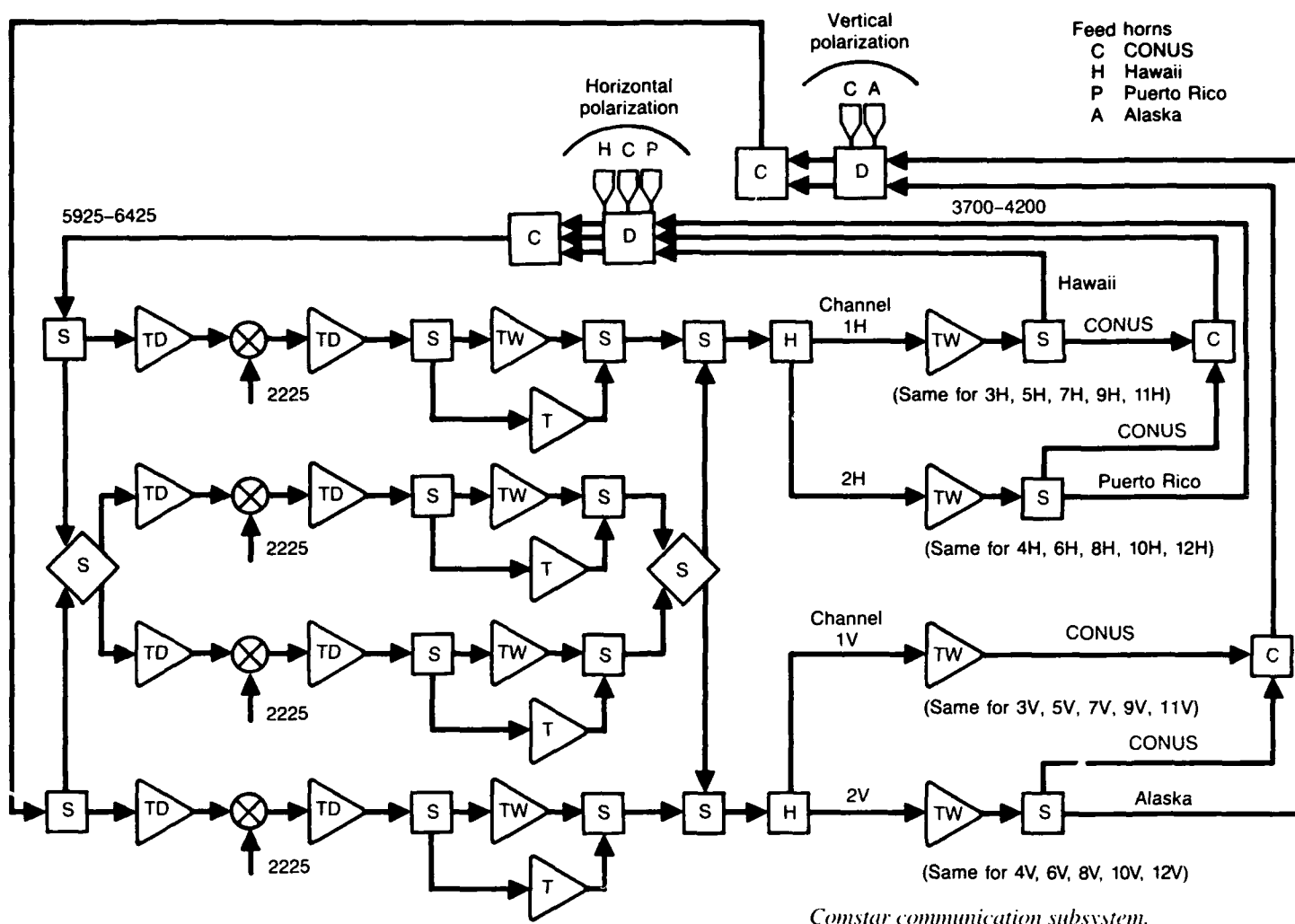
Operated by Comsat General Corporation

The communications subsystem was a new design relative to Intelsat IV and has twenty-four channels. Twelve channels plus the guardbands between them almost filled the 500-MHz band, so the band was reused by receiving and transmitting twelve channels with horizontal polarization and twelve channels with vertical polarization. Within the satellite, each of these twelve-channel groups used a different receiver; every channel had its own TWT. Separate antennas for each polarization provided coverage of CONUS, while one had additional feed horns for coverage of Alaska and the other for Hawaii and Puerto Rico. Six channels were permanently connected for CONUS coverage. The output of each of the other six channel groups was switchable between one of the outlying areas and CONUS.

In addition to the communication subsystem, the satellites also had beacon transmitters at 19.04 and 28.56 GHz for use in propagation measurements. The data collected in these experiments will be useful in the design of satellites that will use the 18- and 30-GHz bands.

Comsat General Corporation developed these satellites and operated them under a lease agreement with AT&T. The first two satellites were launched in 1976, the third in 1978, and the fourth in 1981. After the fourth launch, the two older satellites were collocated for a time to be operated as a single satellite. Each provided half of the twenty-four repeaters. At the end of 1983, one satellite was turned off and the two older satellites moved. Use of the remaining three satellites decreased as the Telstar 3 satellites were brought into operation, but the fourth Comstar was still being used in 1986.

The second generation of satellites in the AT&T system are called Telstar 3. (Telstar 1 and 2 were two experimental satellites launched in 1962 and 1963.) They were obtained directly by AT&T rather than through the lease arrangement used for the Comstars. The Telstar 3 satellites have the same configuration as Anik C and SBS. The basic external features shown in the left side of the figure are the 6-ft antenna, the main body, which contains all the equipment, and the lower, deployable, solar array. The clear band in the middle of the main body solar array is a thermal radiator, which is closely coupled to the power amplifiers of the communication subsystem. The satellite details are as follows:



Satellite

Cylinder, 85-in. dia., 269-in. height (22.4 ft) in deployed condition

1438 lb in orbit, beginning of life

Solar cells and NiCd batteries, 917 W beginning of life, 670 W end of life

Spin-stabilized, gyrostabilized, approximately 60 rpm, ± 0.08 -deg antenna pointing accuracy

Solid rocket motor for apogee maneuver, liquid monopropellant for on-orbit use

Configuration

Twenty-four 36-MHz bandwidth single-conversion repeaters, dual-polarization frequency reuse

Capacity

Up to 7800 one-way voice circuits or one or two TV signals or thirty 1.544 Mbps digital signals per repeater

Transmitter

3702 to 4198 MHz

Eighteen transistorized amplifiers and twelve TWTs in six groups to provide four active and one spare amplifier for every four repeaters, 5.5 W per amplifier

33-dBW ERP per repeater at edge of coverage

Receiver

5927 to 6423 MHz

Two active plus two spare receivers

≥ -5 dB/K G/T at edge of coverage

Antenna

Two 72-in.-dia. paraboloids with polarizing grids, one behind the other; vertical polarization has twelve feed horns for CONUS beam and two for Alaska; horizontal polarization has four feed horns for CONUS beam and one each for Hawaii and Puerto Rico

Design life

Ten years

Orbit

Synchronous equatorial, stationkeeping to $\pm 0.05^\circ$ N-S and E-W

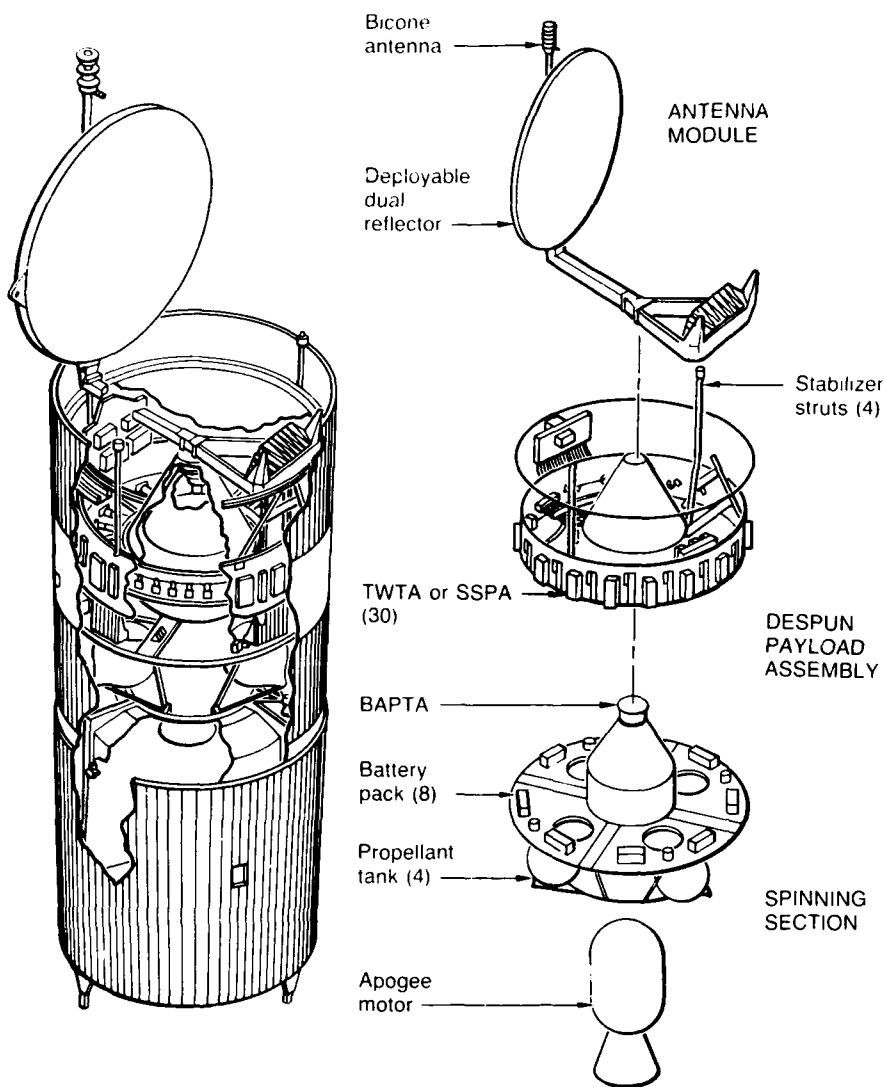
Orbital history

301 (3A): launched 28 July 1983, in use, 96° W longitude

302 (3B): launched 30 August 1984 (deployed from Shuttle, 1 September), in use, 85° W longitude

303 (3C): launched 17 June 1985 (deployed from Shuttle, 19 June), in use, 125° W longitude

Delta 3920/PAM launch vehicle (301), Shuttle/PAM launch vehicle (302, 303)



Telstar 3 satellite details.

Management

Developed by Hughes Aircraft Company for AT&T
Operated by AT&T

The communication subsystem is functionally the same as that of the Comstar satellites. It has twenty-four channels that use dual polarization transmission and reception. Of the twenty-four channels, six are always connected to the CONUS transmit beam; the other sets of six are switchable between the beams for CONUS and other areas. Internally, there are two main changes from the Comstar communication subsystem. One is the addition of the six spare amplifier chains. The other is the use of solid-state amplifiers. Eighteen of the thirty power amplifiers are constructed with field effect transistors—a single first stage followed by three successive stages, each with two parallel transistors. The other twelve amplifiers are TWTs.

Development of the Telstar 3 satellites started in 1980. The first was launched in July 1983, the second in August 1984, and the third in June 1985. Traffic was transferred from the older Comstars to the Telstars, with AT&T maintaining a four-satellite system composed of three Telstars and one Comstar. AT&T considered a fourth Telstar but dropped the idea for two reasons: the capacity available in a nationwide fiber optics network the com-

pany was building, and new ways of using satellite channels to increase their capacity.

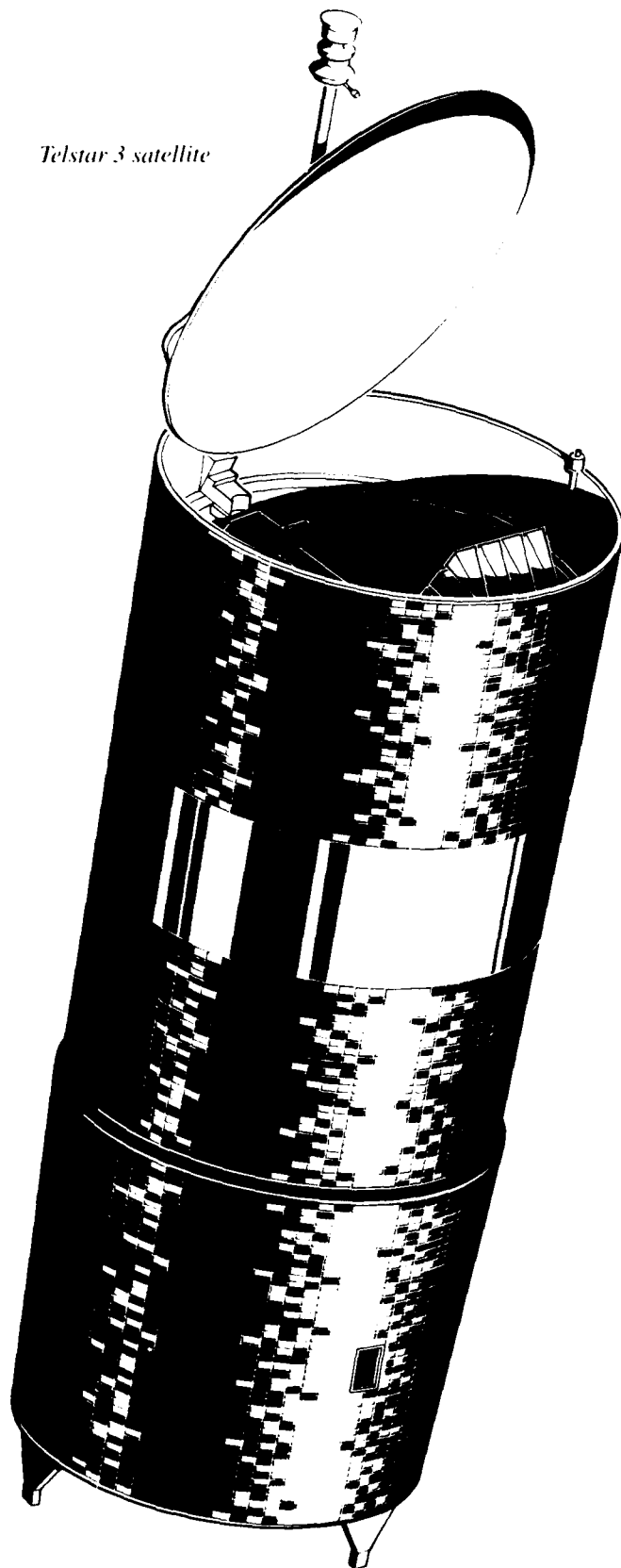
The Telstar 3 satellites are being operated by AT&T. Satellite control equipment has been added to an existing AT&T ground terminal in Pennsylvania. Equipment was also added to an existing terminal in California as a backup to the primary site. Eight other communication terminals, not all operated by AT&T, comprise the basic network. Links between these terminals are either part of the public telephone network or the private telephone network operated by AT&T for the government. The use of the Comstar satellites was restricted to these two applications during the 1976 to 1979 period to allow other domestic satellite companies an opportunity to establish themselves before facing direct competition from AT&T.

Since 1979, AT&T has been free to use its satellites for any type of communications. Long-distance, high-capacity voice links are still a major source of traffic, but television distribution is increasing. The television services include both regular network television and occasional uses. Other traffic includes high-speed data and video conferencing. Because of their interest in high-capacity voice transmission, AT&T has made use of companded single-sideband modulation. This modulation, combined with the large earth terminals, allows 6000 or more voice circuits per 36-MHz

satellite channel, compared to the typical 1000 to 1500 voice circuits with single-carrier FDM/FM in other systems.

The lifetimes of the Telstar 3 satellites require replacement satellites to be launched beginning about 1992 or 1993. In planning for these replacements, AT&T attempted to buy satellites being

Telstar 3 satellite



developed by Ford Aerospace, but the FCC would not transfer the authorization for these satellites to AT&T. Thus, AT&T had to file a request for a new authorization, which was granted in November 1988, just after receiving manufacturers' proposals for the satellites. A contract was awarded in autumn 1989 for three Telstar 4 satellites, two to be launched and one to be a ground spare.

The satellites are larger than previous domestic communications satellites and have twice the bandwidth of the Telstar 3s. The Telstar 4 satellites use both C-band (6/4 GHz) and Ku-band (14/12 GHz). The C-band equipment is similar to the entire communications subsystem on Telstar 3, consisting of twenty-four transponders with 36-MHz bandwidths. The Ku-band equipment has sixteen transponders with 54-MHz bandwidths. Eight of these can be individually switched to become two 27-MHz bandwidth transponders, so the satellite can have a maximum of twenty-four Ku-band transponders. In C-band, two transmitter power levels are available in every amplifier. In Ku-band, two power levels are available by using either one or two amplifiers per transponder on up to twelve transponders simultaneously. To power all of these amplifiers, the Telstar 4 satellites have the highest power-generating capacity of any communications satellite. In addition, they will be the first to use electric arc jets for stationkeeping, which allows a weight reduction relative to using liquid propulsion for that function. Additional satellite and communications characteristics are:

Satellite

Body 7 × 8 × 10 ft, span of solar arrays 80 ft

Approximately 3700 lb in orbit, beginning of life

Sun-tracking solar arrays and NiH₂ batteries, 7200 W at beginning of life

Three-axis stabilization using momentum wheels and magnetic torquers, ±0.1 deg accuracy in roll and pitch, ±0.25 deg in yaw

Bipropellant liquid propulsion for apogee maneuver and on-orbit use plus arc jets for north-south stationkeeping

Configuration

C: twenty-four 36-MHz bandwidth single-conversion transponders, dual-polarization frequency reuse

Ku: sixteen 54-MHz bandwidth transponders, eight can individually be switched to become two 27-MHz bandwidth transponders, dual-polarization frequency reuse

Transmitter

C: 3700 to 4200 MHz

Dual power level (11 or 21 W) solid-state power amplifiers arranged in four groups of seven with six active and one spare

ERP 35/38 dBW (11/21 W) over the contiguous 48 states, lower for Alaska and the Caribbean

Ku: 11.7 to 12.2 GHz

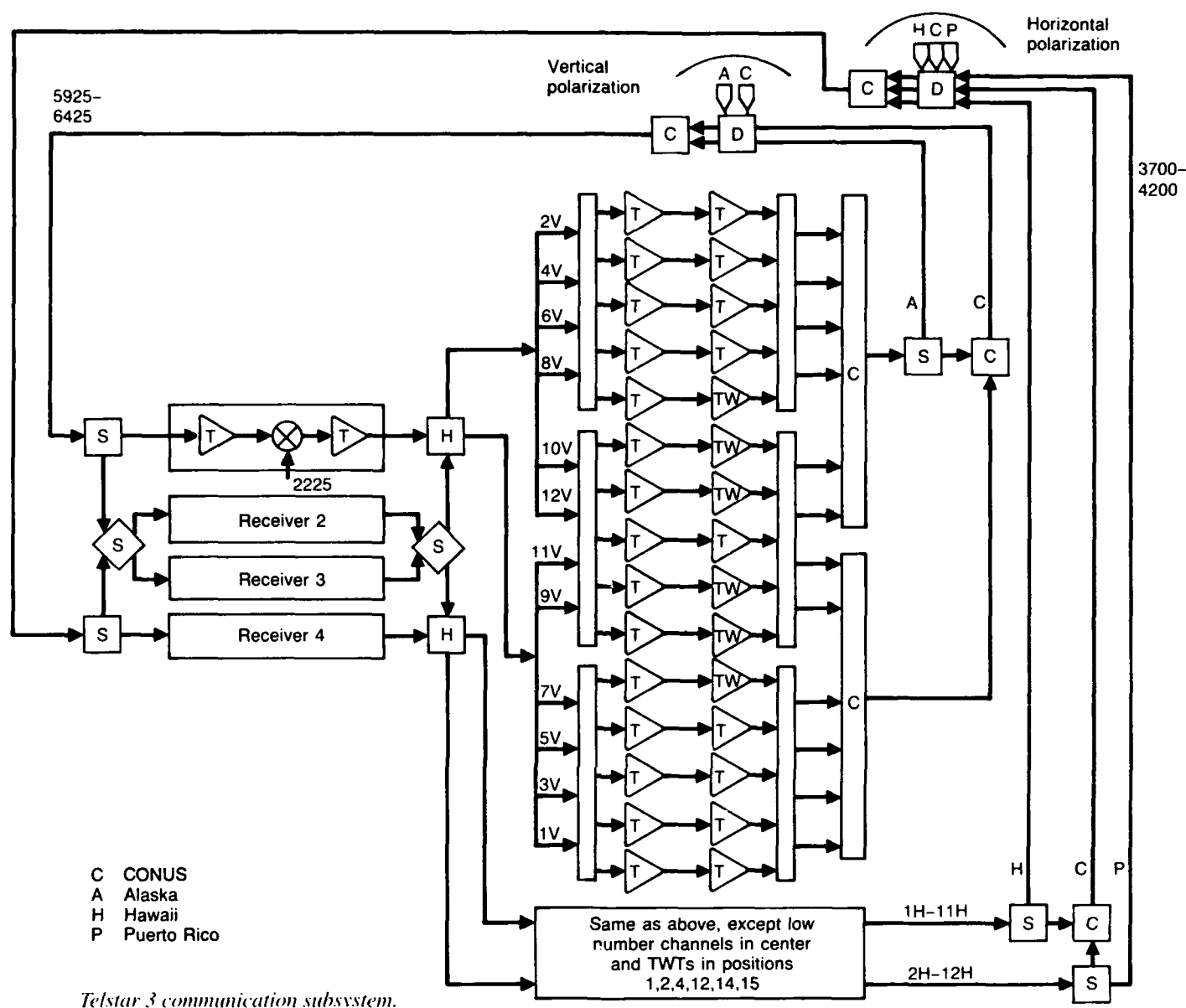
60-W TWTAs arranged in two groups of eighteen, one per transponder, or two in parallel per transponder on up to six transponders per group; number of spares varies with number of transponders (54 versus 27 MHz bandwidths) and number of paralleled TWTAs

ERP 44.3/47.1 dBW (one/two TWTAs)

Receiver

C: 5925 to 6425 MHz

Two active plus two spare receivers



Ku: 14.0 to 14.5 GHz
 HEMT preamplifiers
 Two active plus two spare receivers

Antenna

Two offset-fed parabolic reflectors, each beam covers the 50 states plus Puerto Rico and the Virgin Islands, alternate spot beam for Hawaii (for six C-band transponders), dual linear polarizations

Design life

Twelve years

Orbit

Synchronous equatorial, 89°W and 97°W longitude, stationkeeping to $\pm 0.05^\circ$ N-S and E-W

Orbital history

401: launch scheduled February 1993

402: launch scheduled early 1994

Atlas II launch vehicle

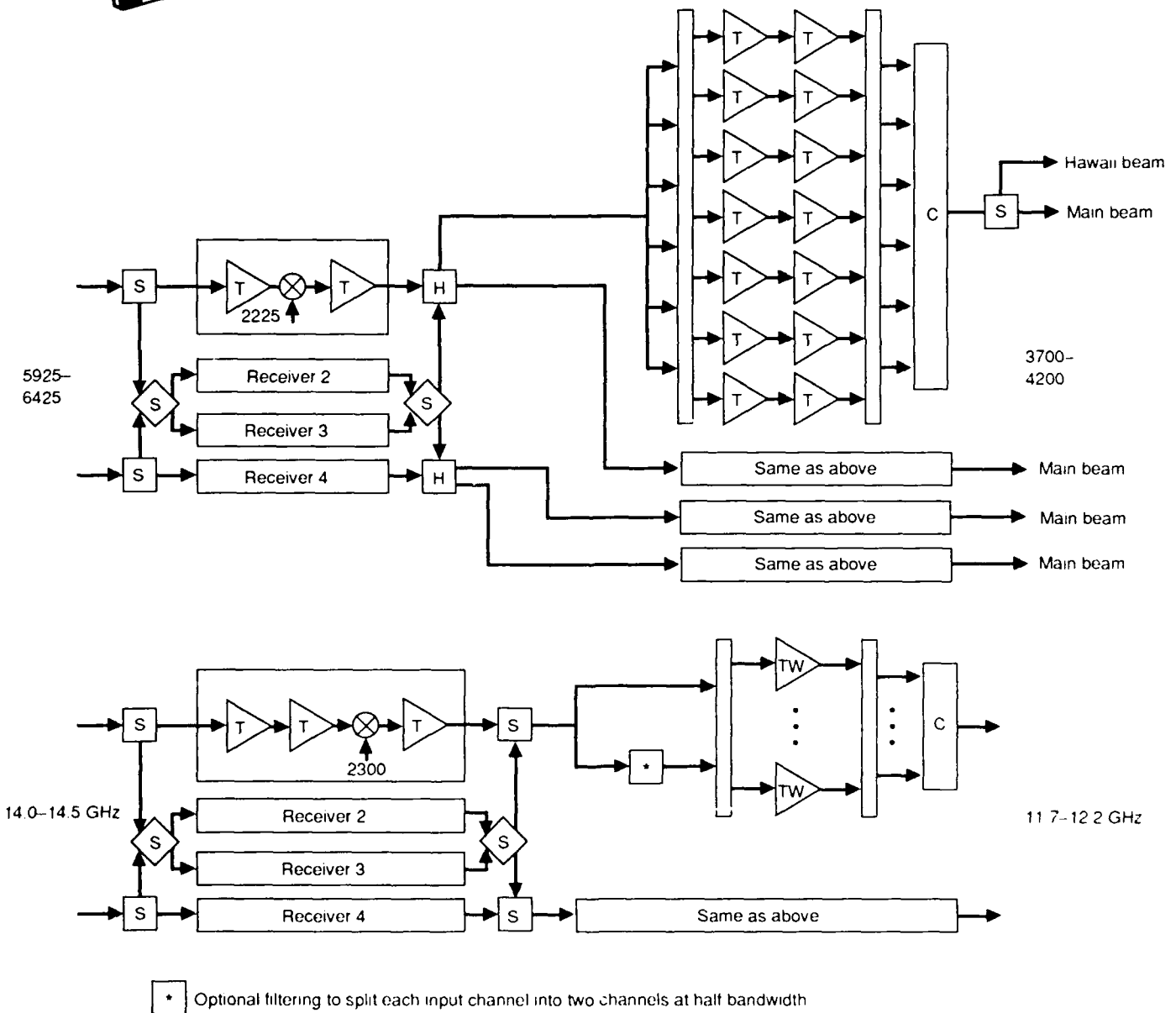
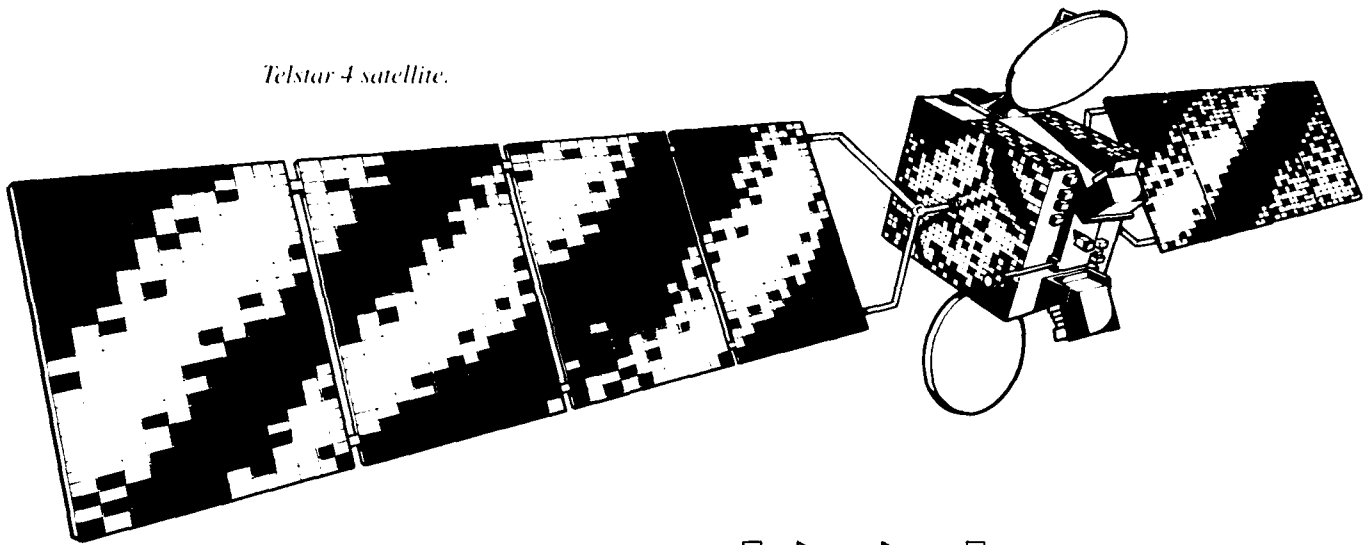
Management

Developed for AT&T by GE Astro Space

Operated by AT&T

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Telstar 4 satellite.



Telstar 4 communication subsystem.

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12. R. F. Latter, "AT&T/GSAT Domestic Satellite Operational Network," Paper 80-0515, *AIAA 8th Communications Satellite Systems Conference* (April 1980).
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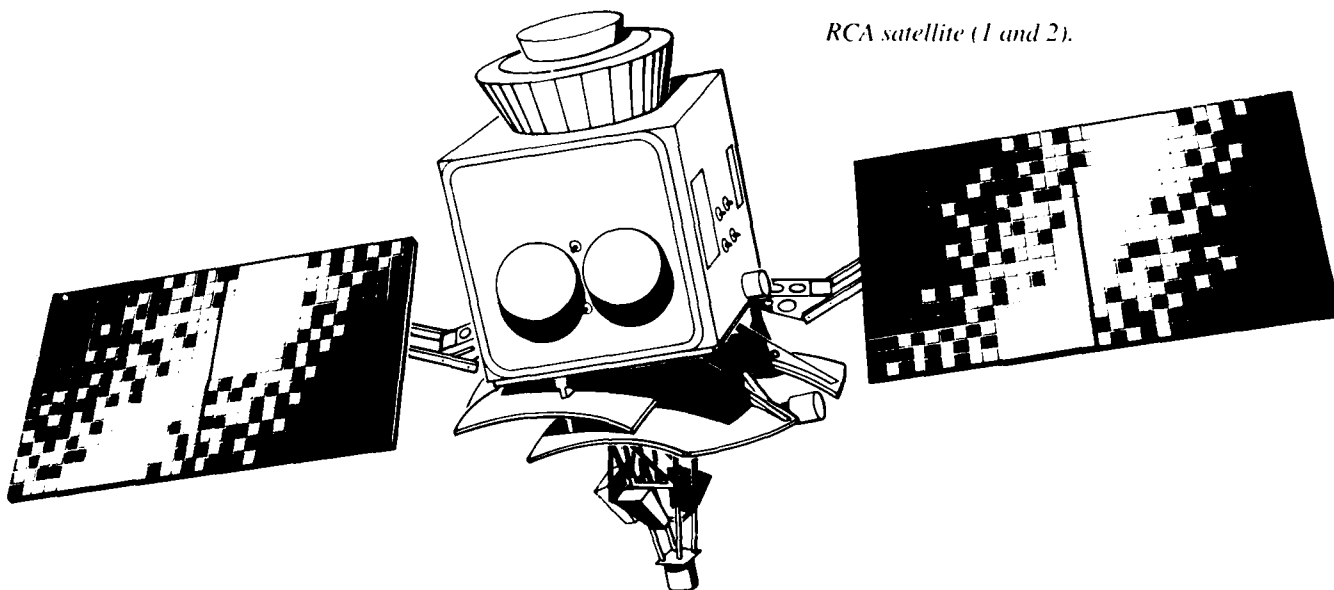
GE/RCA

RCA Corporation, through several subsidiary companies (all with the RCA name), developed domestic communications satellites [1-30] and is using them for its own communications network and for lease or sale to others. After RCA was bought by General Electric in 1986, all of the subsidiaries gradually changed the RCA part of their names to GE. GE has two types of satellites: the C-band satellites have been in orbit since 1975 and have been improved several times; the Ku-band satellites were added in 1985.

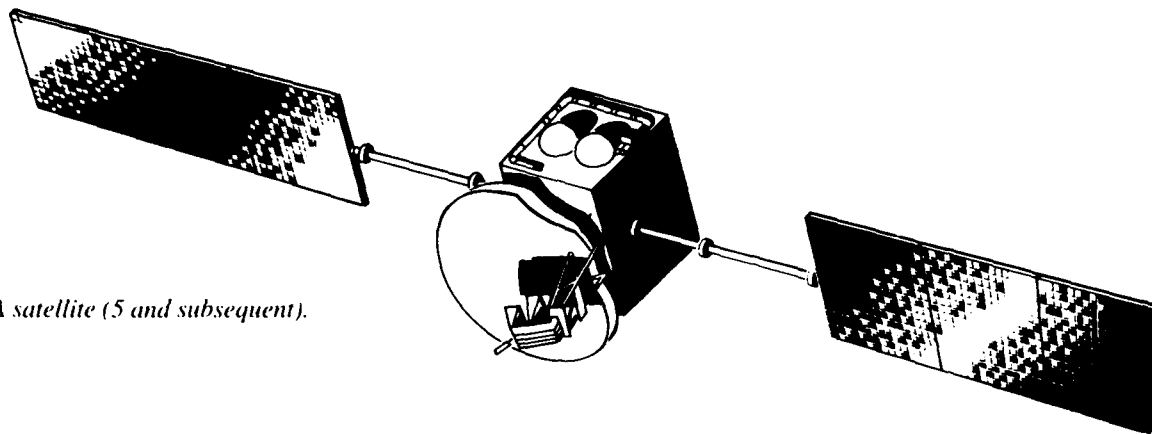
The GE C-band satellites have a boxlike body. Solar panels are deployed in orbit from two opposing sides of the body, while the antennas are mounted on the earth-facing side. The satellite body is stabilized to keep the antennas earth oriented, and the solar arrays are rotated about their axes to track the sun.

These satellites have evolved over the years. All have similar designs, but their sizes have increased, and additional equipment has resulted in increased reliability and life. The early satellites had two sections in each of the two solar panels, whereas the newer satellites have three sections in each panel. The increased panel size, together with increased solar cell efficiency, enable support of higher power payloads. The satellites' evolution consists of three groups: 1 through 4, launched from 1975 to 1982; 5, 1R, and 2R, launched from 1982 to 1983; and C-1 to C-4, launched beginning in 1990. The RCA/GE designation for all of these satellites is Satcom, e.g., Satcom 1R. Satellite details are as follows, with C designating C-1 through C-4:

RCA satellite (1 and 2).



RCA satellite (5 and subsequent).



Satellite

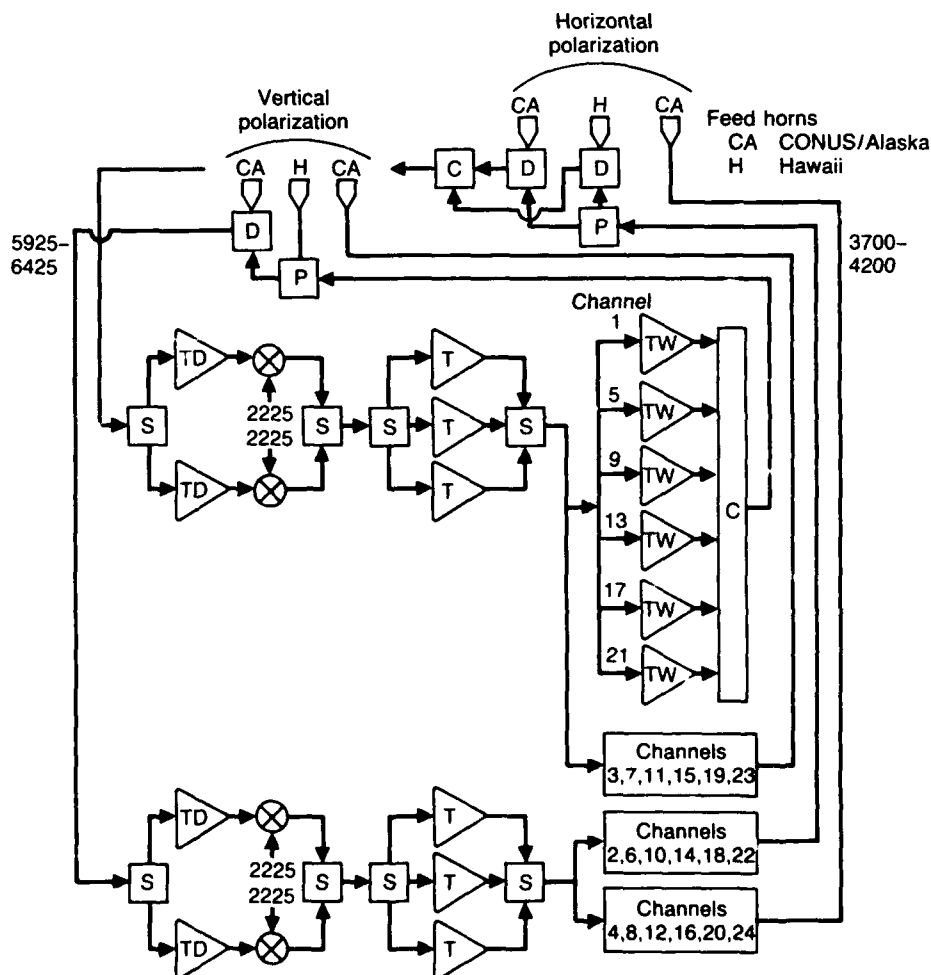
Box, $47 \times 64 \times 44$ in. (1, 2, 3, 3R, 4), $56 \times 64 \times 69$ in. (5, 1R, 2R), $50 \times 64 \times 52$ in. (C) with antenna and feeds fixed on one end and solar panels deployed from two sides, overall span 31.4 ft (1, 2)/40.5 ft (3, 3R, 4)/47.6 ft (5, 1R, 2R); overall height approximately 114 in. (1, 2)/137 in. (5, 1R, 2R)

1020 lb (1, 2), 1280 lb (3, 3R, 4), 1318 lb (5, 1R, 2R, C) in orbit, beginning of life

Sun-tracking solar array and NiCd (1, 2, 3, 3R, 4, 5, 1R, 2R)/NiH₂ (C) batteries, 745 W (1, 2)/1000 W (3, 3R, 4)/1470 W (5, 1R, 2R) at beginning of life, 490 W (1, 2)/700 W (3, 3R, 4) minimum after eight years, 980 W (5, 1R, 2R) minimum after ten years, 1029 W (C) after twelve years

Three-axis stabilization using momentum wheels and magnetic torquers, ± 0.2 -deg accuracy (1, 2, 3, 3R, 4); improving to ± 0.05 deg (C)

RCA communication subsystem (1 through 3).



Note:

Satellites from 3 on have a spare amplifier for each group of 6

Solid rocket motor for apogee maneuver, monopropellant liquid propulsion for on-orbit use

Configuration

Twenty-four 34-MHz bandwidth single-conversion repeaters, dual polarization frequency reuse

Capacity

Up to 1000 (1, 2, 3, 3R, 4), 6000 (5, 1R, 2R) one-way voice circuits or 64 Mbps data or two TV programs per repeater

Transmitter

3700 to 4200 MHz

One 5-W TWT per repeater, no redundancy (1, 2)

One 5.5-W TWT for each of eighteen repeaters plus one spare per six repeaters and one 8.5-W TWT for each of six repeaters plus one spare (3, 3R, 4)

One 8.5/9.5-W transistor amplifier per repeater plus one spare per six repeaters (5, 1R, 2R/C)

ERP per repeater at edge of coverage: 32 dBW (CONUS and Alaska), 26 dBW (Hawaii) (1, 2, 3, 3R, 4); 34 dBW (CONUS and Alaska), 35 dBW (CONUS), 37 dBW (Alaska), 26 dBW (Hawaii) (5, 1R, 2R, C)

Receiver

5925 to 6425 MHz

Four receivers (two on, two standby)

Tunnel diode preamplifier, 7-dB noise figure (1, 2); FET preamplifier, 3.5-dB noise figure (3, 3R, 4, 5, 1R, 2R)

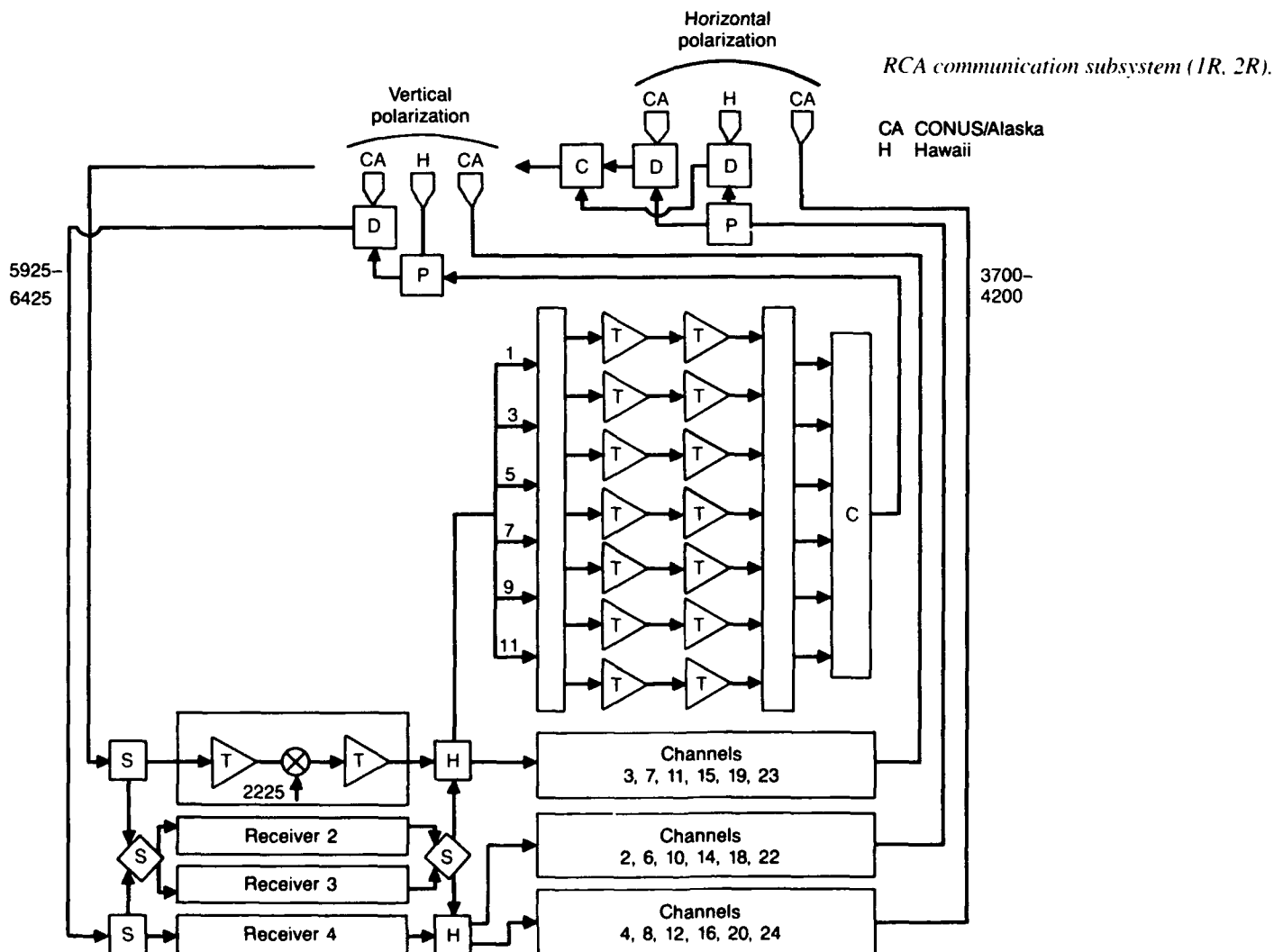
G/T at edge of coverage: -6 dB/K (1, 2, 3, 3R, 4), -3 dB/K (5, 1R, 2R, C) (CONUS and Alaska); -10 dB/K (1, 2, 3, 3R, 4), -13 dB/K (5, 1R, 2R, C) (Hawaii)

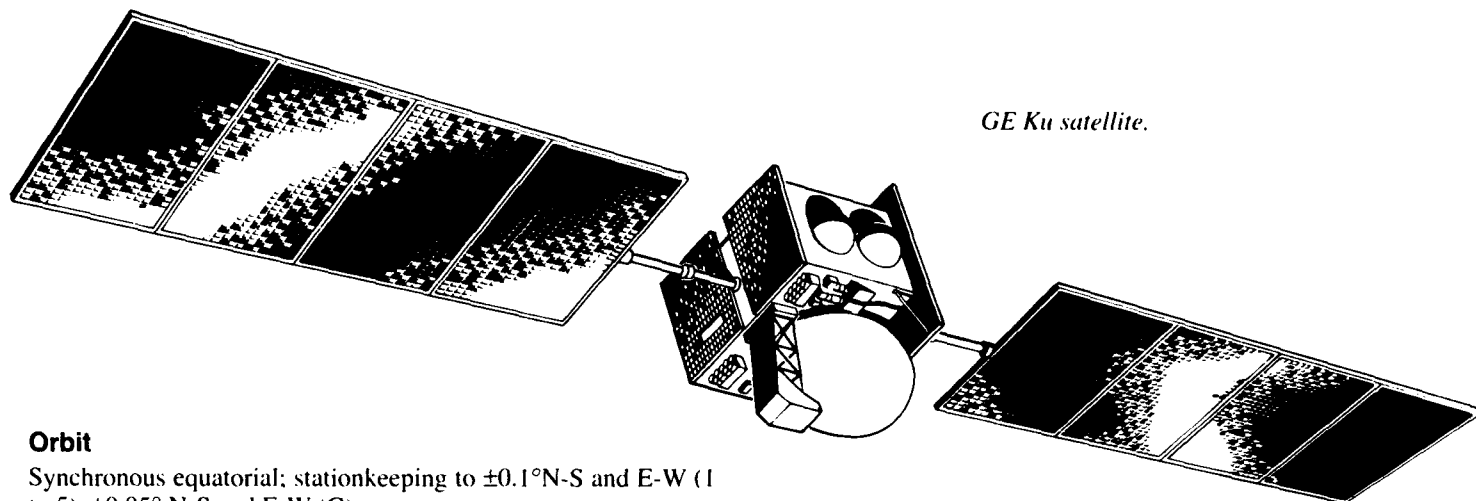
Antenna

One antenna with overlapping gridded reflectors, one for horizontal polarization transmission and reception and one for vertical polarization, each with feed horns for CONUS/Alaska coverage and for Hawaii coverage. (Satellite 5 has only Alaska/Hawaii coverage on horizontal polarization), one (1, 2)/six to seven (5, 1R, 2R, C) feed horns per polarization, 33-dB isolation between the two polarizations

Design life

Seven years (1, 2)/eight years (3, 3R, 4)/ten years (5, 1R, 2R)/twelve years (C)





GE Ku satellite.

Orbit

Synchronous equatorial; stationkeeping to $\pm 0.1^\circ$ N-S and E-W (I to 5), $\pm 0.05^\circ$ N-S and E-W (C)

Orbital history

- 1: launched 13 December 1975, replaced by 1R in summer/fall 1983, turned off June 1984 and moved above synchronous orbit
- 2: launched 26 March 1976, replaced by 2R in the fall of 1983, then turned off and moved above synchronous orbit
- 3: launched 7 December 1979, lost at apogee motor firing
- 3R: launched 19 November 1981, in use, 131° W longitude
- 4: launched 15 January 1982, in use, 82° W longitude
- 5: launched 28 October 1982, in use, 143° W longitude, named Aurora

1R: launched 11 April 1983, in use, 131° W longitude

2R: launched 8 September 1983, in use, 72° W longitude

Delta 3914 (1, 2)/3910 (3, 3R, 4)/3924 (5, 1R, 2R) launch vehicle

C-1: launched 20 November 1990, in use, 139° W longitude

C-2: launch schedule uncertain

C-3: launch schedule uncertain

C-4: launch schedule mid 1992

Ariane launch vehicle (C-1, C-3, C-4)

Management

Developed by GE Astro Space (formerly RCA Astro Electronics) for Americom and RCA Alascom (Alascom Inc., since 1981)

Operated by GE (formerly RCA) Americom

The GE satellite C-band communication subsystem is similar to that of the AT&T satellite in that it has twenty-four channels with frequency reuse by orthogonal linear polarizations. The satellite has separate antennas for the two polarizations. The antennas are physically overlapping but each responds to only one polarization because of embedded polarizing grids. On Satellites 1 through 4, the main beam of each antenna has a single elliptical footprint that covers CONUS and Alaska (and the intervening part of Canada). An additional offset feed horn provides a separate beam for coverage of Hawaii. Beginning with Satellite 5, a different feed structure is used, permitting coverage of these two areas and of CONUS alone or Alaska alone. Switching between different coverage patterns is possible. The first satellites used one TWT per repeater with no redundancy. The next set had one spare TWT for each six repeaters, for improved reliability. On the newest satellites, solid-state (FET) amplifiers have replaced the TWTs, again with one-for-six redundancy. These amplifiers have better linearity and lower AM/PM (amplitude to phase modulation) conversion than TWTs, affording up to 50% capacity in-

crease in multiple carrier per repeater operation. The original communication subsystem is shown as well as the new subsystem with various improvements.

The first satellites were the first to use the Delta launch vehicle Model 3914. This version of the Delta was developed to meet RCA requirements and was partially funded by RCA, marking the first time a launch vehicle development was privately sponsored. The first launch was in December 1975 and the second in March 1976. A third launch in 1979 was unsuccessful; the satellite was destroyed during apogee motor firing. Since then, there have been five successful launches, one in 1981 and two each in 1982 and 1983.

The two satellites launched in 1983, generally called 1R and 2R, have replaced the first two. Satellite 3R, which replaced the one destroyed, and Satellite 4 are also actively used by GE. Satellite 5 was sold, prior to launch, to Alascom, Inc. which provides long-distance communications within Alaska and between Alaska and other states. Aurora II, described later, will replace Satellite 5 for Alaskan service. Satellite C-1, launched in 1990, replaced 1R, which was moved to colocate it with 3R. These two satellites, along with 2R and 4, will be replaced by C-2 through C-4 by 1993.

GE takes care of satellite command and telemetry for both its own satellites and the Alascom satellite. The primary control site is integrated with a communications terminal in New Jersey. Another control site in New Jersey was activated in 1985. A secondary control site is integrated with another communications terminal in Southern California. GE has about twelve major communications terminals for commercial traffic of all types. GE also owns about twenty-five terminals in its government services network.

The commercial terminals handle primarily voice and data traffic. The government services network is all data with link rates varying from 56 kbps to 50 Mbps. The primary customer is NASA. The biggest use of the GE satellites is for distribution of television programming. Two satellites are wholly assigned to this service, and several channels on other satellites are also used. Transmission techniques in the GE system include FM/TV, with either one or two channels per transponder, FDM/FM/FDMA for multiple voice circuits, SCPC/QPSK for data, and SCPC/FM for voice. In recent years, companded SSB has begun to displace FDM/FM for high-capacity voice trunks, since the number of voice circuits per transponder can be increased three to four times. Error correction coding is used on many links. TDMA is used in a network that provides voice and data communications for the government.

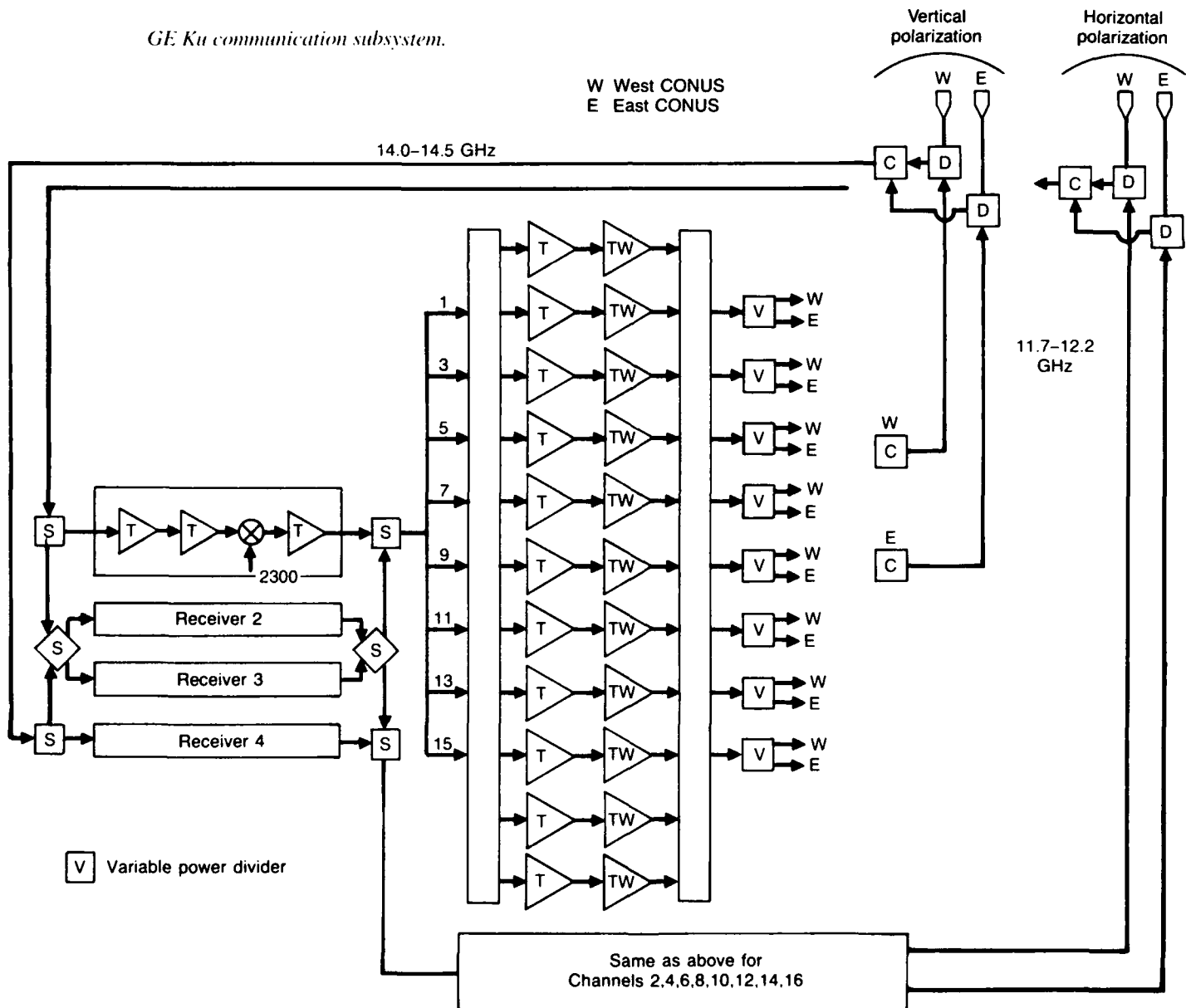
The GE Ku-band satellites look similar to the C-band satellites. The stabilization subsystem has been improved to improve pointing accuracy. Electrothermal hydrazine thrusters, also used on Satellites C-1 through C-4, have replaced four catalytic hydrazine thrusters for more efficient stationkeeping maneuvers. Heat pipes have replaced heat spreaders on the north and south faces of the body, where the communication subsystem is mounted. This reduces weight and improves thermal control. The solar array has four panels per side, rather than three on the C-band satellites, because of the larger power requirement of the communication subsystem.

The communication subsystem has sixteen channels, each with a 54-MHz bandwidth. The first-stage amplifier in the receiver is an FET thermoelectrically cooled to -50°C to reduce system noise. This is the first time a thermoelectric cooler has been used in a long-life communication satellite. The TWTs have a power rating of 45 W—an increase from the power levels used on other satellites. Within the communication subsystem, the channels are handled in two groups of eight. Each group has three spare TWTs.

After the TWT, each channel has a variable power divider, which can send the power to the east beam or the west beam or to both. The separation between the east and west beams is approximately a line from the west side of Minnesota to the western tip of Texas. Thus, each beam roughly matches two time zones. Together, the beams provide CONUS coverage. All reception uses CONUS coverage. The satellites do not have beams for Alaska or Hawaii.

Two Satcom Ku satellites have been launched, late in 1985 and early in 1986. Uses of these satellites are similar to those for the C-band satellites. Ground antenna diameters of 3 to 6 ft provide equivalent reception quality to 10- to 15-ft antennas at C-band. Another benefit of Ku-band is that interference from terrestrial uses of the spectrum is not the problem that it is in C-band, so Ku-band antennas have fewer siting constraints. The third and fourth Satcom Ku satellites were being built for a joint venture with Home Box Office (a cable television company). They were to be dedicated to television distribution to cable systems. However, this business plan was changed, and the partially built satellites were offered for sale. They were bought separately, modified

GE Ku communication subsystem.



for their new owners, and became Luxembourg's Astra 1B and Intelsat K. Characteristics of Ku Satellites 1 and 2 are as follows:

Satellite

Rectangular body, approximately $5\frac{1}{2} \times 7 \times 7$ ft, overall height, including antenna feed tower, 10 ft, span of deployed solar array >50 ft

Approximately 2060 lb in orbit

Sun-tracking solar array and NiH_2 batteries, approximately 3000 W at beginning of life, approximately 2500 W after ten years

Three-axis stabilization using momentum wheels and magnetic torquers, ± 0.05 -deg antenna pointing accuracy

Solid rocket motor for apogee maneuver, liquid monopropellant propulsion for on-orbit use

Configuration

Sixteen 54-MHz bandwidth repeaters, dual-polarization frequency reuse

Transmitter

11.7 to 12.2 GHz

One 45-W TWT per repeater, three spares per eight repeaters
ERP per repeater

CONUS: 38 dBW (minimum) 43 dBW (>95% of CONUS)

West: 45 dBW (minimum), most areas 46 to 48 dBW

East: 39 dBW (minimum), most areas 45 to 47 dBW

Receiver

14.0 to 14.5 GHz

Four receivers (two on, two standby)

Cooled FET preamplifier, 2-dB noise figure

Antenna

Two reflectors (one for horizontal and one for vertical polarization), 60-in. diam, each with nine feed horns for east coverage and five for west coverage (all feeds combine for CONUS coverage)

Design life

Ten years

Orbit

Synchronous equatorial, stationkeeping to $\pm 0.1^\circ$ N-S and E-W

Orbital history

2: launched 27 November 1985 (deployed from Shuttle, 28 November), in use, 81° W longitude

1: launched 12 January 1986 (deployed from Shuttle, 12 January), in use, 85° W longitude

Shuttle launch vehicle (1, 2)

Management

Developed by RCA Astro Electronics for RCA Americom

Operated by RCA Americom (now GE Americom)

* * * * *

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Satellite Business Systems

Satellite Business Systems (SBS) was the fourth domestic system to be authorized [1-17] and the first to use the 12- and 14-GHz frequencies. When the system was authorized, IBM, Aetna, and Comsat Corporation each owned one-third of SBS. In 1984, Comsat sold its shares to the other two partners. In 1985, IBM and Aetna sold SBS to MCI Communications Corporation. Aetna received cash and IBM received MCI stock plus ownership of SBS Satellites 4 through 6. IBM transferred these three satellites to a subsidiary, IBM Satellite Transponder Leasing Corporation. This subsidiary and its three satellites were sold to Hughes Communications in 1989. Among the SBS satellites, the first five have the same design; SBS 6 is larger and has more channels and higher performance.

SBS Satellites 1 through 5 are very similar in design to Anik C and several other domestic satellites. During launch, the satellite is a compact cylinder. In orbit, the antenna unfolds from one end of the satellite, and a cylindrical solar array is deployed axially at the other end. When the solar array is deployed, it reveals the main cylindrical body of the satellite, which is also covered with solar cells except for a mirrored band that serves as a thermal radiator. The satellite details are as follows:

Satellite

Cylinder, 85-in. dia., 260-in. height (21.7 ft) in deployed condition

1220 (1-4)/approximately 1360 (5) lb in orbit, beginning of life
Solar cells and NiCd batteries, 900 (1-4)/approximately 1000 (5) W nominal, approximately 830 (1-4) W minimum after seven years

Spin-stabilized, gyrostabilized, 50 to 90 rpm (50 rpm nominal), antenna pointing to better than 0.05 deg

Solid rocket motor for apogee maneuver, monopropellant liquid propulsion for on-orbit use

Configuration

Ten 43-MHz bandwidth single-conversion repeaters (1-5), plus four 110-MHz bandwidth single-conversion repeaters on the orthogonal polarization (5)

Transmitter

11.703 to 12.188 GHz

One 20-W TWT per repeater plus six (1-4)/ten (5) spares per sat-

ellite, five channels may be switched to use two TWTs in parallel (5)

Minimum 40.0-dBW ERP over most of CONUS, 41.7 dBW over most of the eastern third of CONUS (1-4)

Receiver

14.003 to 14.488 GHz

Redundant receivers (one on, three spare)

≥ -2.5 dB/K G/T over most of CONUS, ≥ 0 dB/K over most of the eastern third of CONUS

Antenna

Two 72-in.-dia. paraboloids occupying the same aperture and with orthogonal linear polarizations, beam shaped for CONUS coverage and weighted to emphasize eastern part of CONUS (see SBS coverage regions figure for details), ten transmit and fifteen receive feed horns, additional feed horns for Alaska and Hawaii (5)

Design life

Seven (1-4)/ten (5) years

Orbit

Synchronous equatorial, stationkeeping to $\pm 0.03^\circ$ N-S and E-W (goal), ± 0.05 deg (maximum)

Orbital history

1: launched 15 November 1980, spare in 1986, moved above synchronous orbit in 1990

2: launched 24 September 1981, in use, 97° W longitude, 3-deg inclination in 1991

3: launched 11 November 1982, in use, 95° W longitude

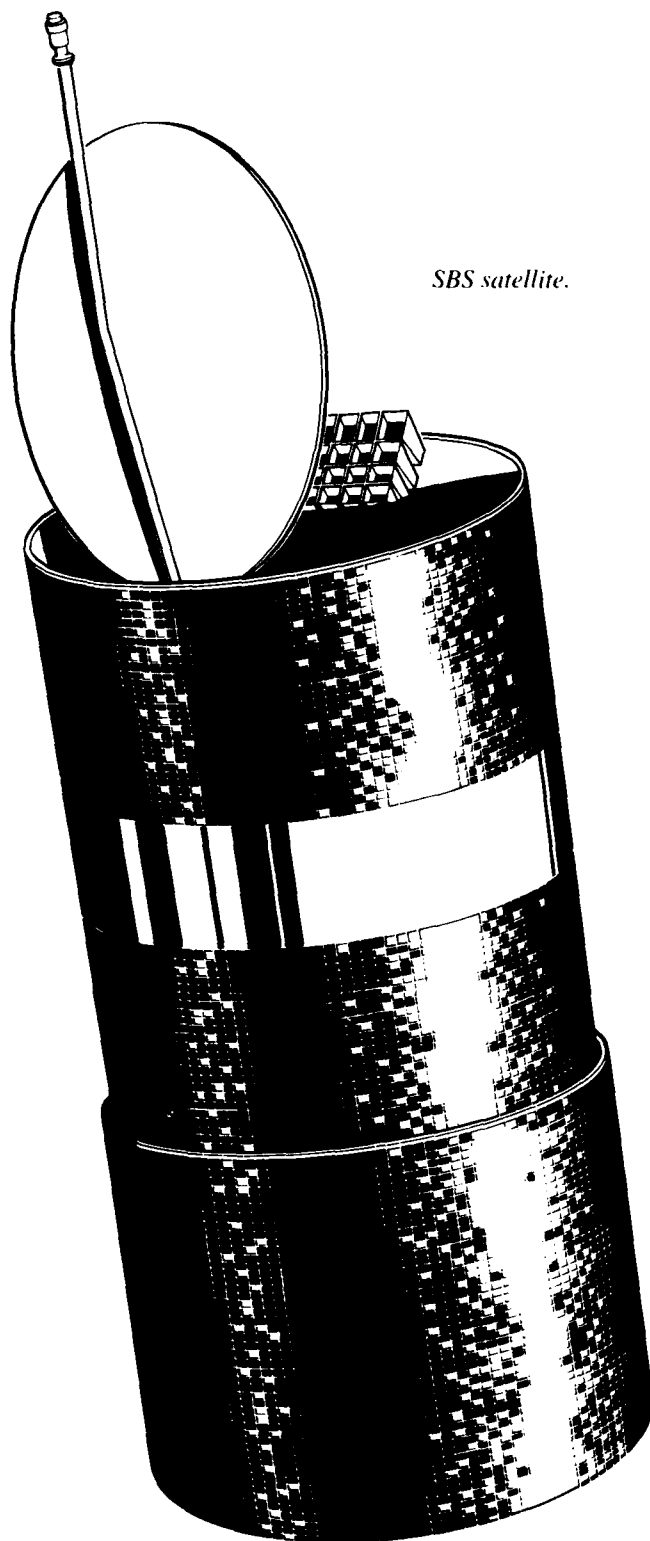
4: launched 30 August 1984, (deployed from Shuttle, 31 August), in use, 91° W longitude

5: launched 8 September 1988, in use, 123° W longitude

Delta 3910/PAM launch vehicle (1 and 2), Shuttle/PAM (3 and 4), Ariane/PAM (5)

Management

Developed by Hughes Aircraft Company for Satellite Business Systems



SBS satellite.

The communication subsystem is relatively simple. It has ten channels that use a common broadband receiver and individual transmitters. There are sixteen transmitter sections, each consisting of a low-level amplifier and a 20-W TWT connected through switching networks to provide six spares for the ten channels. The antenna is hinged for deployment and for north-south pointing. East-west pointing is accomplished by adjusting the pointing of the despun communications equipment shelf on which the antenna is mounted. Pointing control is derived from signals produced by a four-horn monopulse network integrated with the regular receive horns. The receiving and transmitting antenna feeds are

separate multihorn arrays, which provide a weighted beam that is strongest in the eastern part of the United States, as noted in the SBS coverage regions figure and in Table 1.

The fifth satellite has four additional channels, each with 110-MHz bandwidth. They are accommodated by using receiving and transmitting polarization orthogonal to those used for the basic ten channels. The number of driver amplifiers and TWTs has been increased to twenty-four, providing ten spares on the satellite. Also, the antenna feed structure has been enlarged to provide coverage of Alaska and Hawaii. Satellite weight and power-generating capability have increased slightly to accommodate the extra equipment.

SBS ordered three satellites at the end of 1977 and one more each in 1982, 1983, and 1985. The first was launched late in 1980 and the second in 1981. The third was launched in November 1982 on the first Shuttle flight to deploy commercial payloads, and the fourth was launched in August 1984. All four satellites are operational. The fifth was launched in September 1988.

SBS Satellite 6 is a larger satellite that provides significantly more capacity than the earlier SBS satellites. It appears very similar to the original SBS satellites but is 67% larger in diameter and 42% larger in height. The antenna and the lower solar panel stow for launch and deploy in orbit in the same way as the other SBS satellite. Besides size, the difference in the support subsystems includes a change to a NiH_2 battery and the use of all internal propulsion. The satellite contains a solid propellant perigee stage and a bipropellant liquid subsystem used for perigee augmentation, the apogee maneuver, and on-orbit control.

The communication subsystem uses dual-polarization frequency reuse. Ten channels are on one polarization and nine on the other. Each has a 43-MHz bandwidth. The two input polarizations are connected to two of the four receivers. In the transmitter section, there are thirty driver amplifiers and TWTs. Each channel uses one amplifier set with eleven spares available. The TWT power is 41 W—about twice the power in the previous satellites. Also, as with SBS 5, the antenna pattern includes Alaska and Hawaii. SBS 6 was launched in 1990, although an earlier launch was desired. Other satellite details are as follows:

Satellite

Cylinder, 11.8-ft dia., 11.8-ft height stowed for launch, 30.8-ft height deployed in orbit

Approximately 2400 lb in orbit, beginning of life; approximately 2280 lb after ten years

Solar cells and NiH_2 batteries, 2240-W minimum after ten years

Spin-stabilized, gyrostabilized, antenna pointing to better than 0.05 deg

Unified bipropellant propulsion for perigee maneuver augmentation, apogee maneuver, and on-orbit use

Configuration

Nineteen 43-MHz bandwidth single-conversion repeaters, dual-polarization frequency reuse

Transmitter

11.7 to 12.2 GHz

One 41-W TWT per repeater plus eleven spares per satellite

ERP: ≥ 41 dBW (95% of CONUS), ≥ 44 dBW (most of eastern half of CONUS), 41 to 44 dBW (populous parts of Alaska), 45 dBW (Hawaii)

Receiver

14.0 to 14.5 GHz

Four receivers (two on, two standby)

G/T: ≥ -0.6 dB/K (90% of CONUS), ≥ 1.4 dB/K (most of eastern half of CONUS), -3.6 dB (Hawaii, Alaska)

Antenna

Two 7.9-ft-dia. parabolic reflectors occupying the same aperture and using orthogonal linear polarizations, beam shaped for CONUS plus Alaska with weighting for eastern CONUS, secondary beam for Hawaii

Design life

Ten years

Orbit

Synchronous equatorial, stationkeeping to $\pm 0.03^\circ$ N-S and E-W (goal), ± 0.05 deg (maximum)

Orbital history

6: launched 12 October 1990, 99° W longitude

Ariane launch vehicle

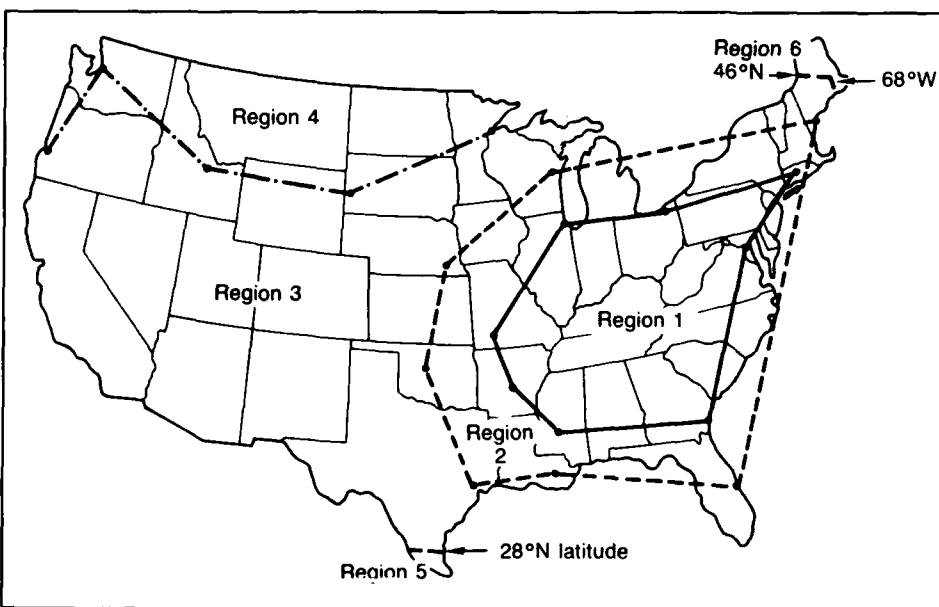
Management

Developed by Hughes Aircraft Company for Satellite Business Systems, sold to Hughes Communications prior to launch

Operated by Hughes Communications

Table 1. Minimum Performance Requirements

REGION	RECEIVE G/T, dB/K	TRANSMIT ERP, dBW
1	+2.0	43.7
2	0	41.7
3	-2.5	40.0
4	-5.5	37.0
5	-4.5	38.0
6	-5.5	39.0
San Francisco	+0.5	42.0
Los Angeles	-0.3	41.2



SBS coverage regions.

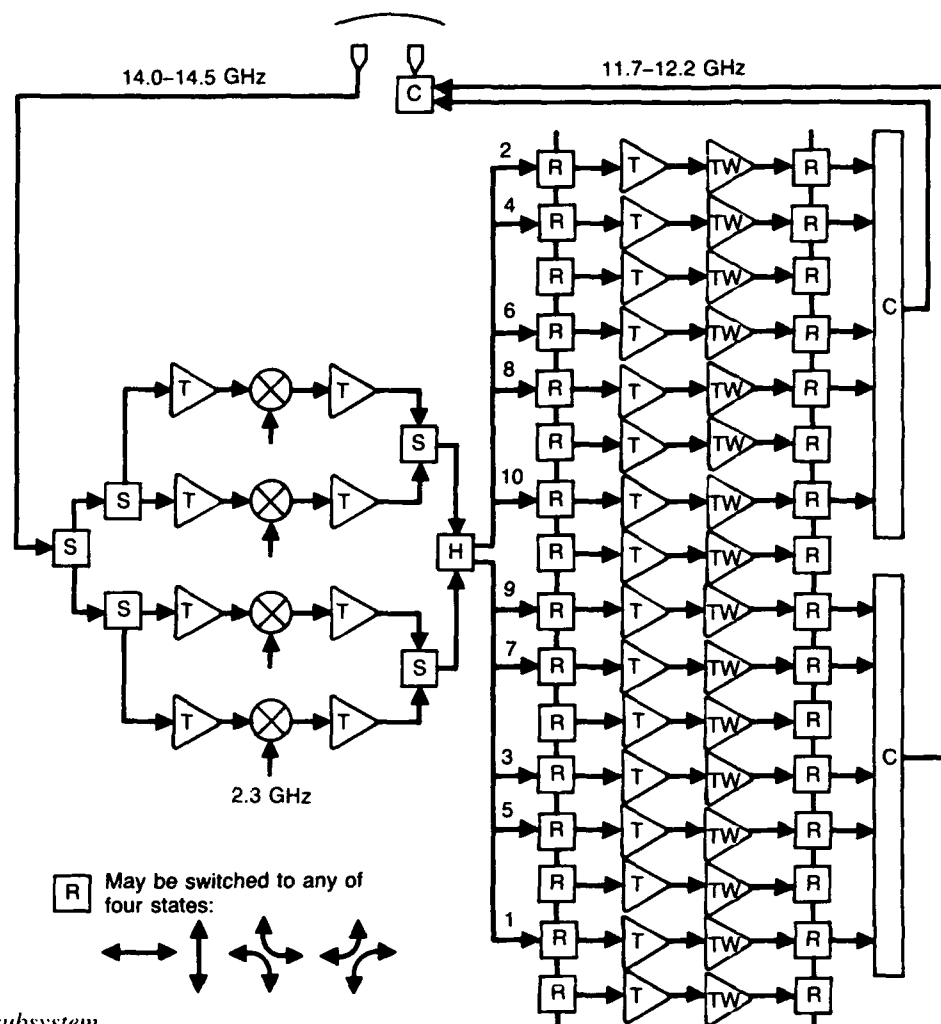
The SBS network was designed to provide integrated voice and data services primarily to large corporations that have facilities at several sites in the United States. The SBS design was unique in serving only CONUS and in using digital, demand-assigned, TDMA links for all transmissions. The system as originally operated followed this plan, with corporate customers served by means of either on-site, dedicated terminals or by sharing a terminal with several customers in a local area. In an effort to increase revenue, SBS began offering long-distance service to residential customers as well.

The services provided to the majority of customers are dedicated digital networks connecting two or more sites. The capacity of the links can be allocated by equipment at the sites among various uses, including voice circuits, video conferencing, and data and facsimile transmissions. For multisite customers, their total network capacity can be allocated among the various possible links to meet changing needs on a daily or long-term basis. SBS also provides general-purpose long-distance communications between a number of their own terminals for residential customers, and for business customers who are too small to justify the equipment necessary for a dedicated network. Other uses of the satellites include a small amount of broadcast television distribution and some occasional-use video conferencing. With the change in ownership to MCI, beginning in 1986 there is a rebalancing of traffic between the satellite links and MCI's terrestrial facilities to optimize the use of each.

The SBS ground terminals include an antenna, an exterior equipment shelter, and some equipment inside a customer's building. Most antennas are about 18 ft in diameter. Some, for use in regions of very high rainfall or lower satellite performance, are about 24 ft in diameter. SBS ordered 200 terminals, half from each of two manufacturers. It installed them as required to serve its customers. In 1984, SBS started operations with the first set of a total of 181 ground terminals being installed for distribution of NBC network television. These terminals have 20- or 26-ft-diameter antennas. MCI plans to expand data service through the satellites by designing networks that can work with smaller terminals than these.

The SBS satellites are controlled from TT&C sites at Castle Rock, Colorado, and Clarksburg, Maryland. Both sites have the same TT&C equipment, but the system data processing and control center is at the Maryland site. The Colorado site is the primary beacon transmitter. The satellites use the received beacon for antenna pointing control.

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SBS 1 through 4 communication subsystem.

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Hughes Communications (Galaxy)

Hughes Communications Inc. (HCI) is a subsidiary of Hughes Aircraft Company. HCI [1-3] began operations in 1983 with the first of its Galaxy satellites and had two more in orbit by the end of the next year. In 1988, it acquired three more satellites in orbit by purchasing Westars III, IV, and V from Western Union. The purchase included a fourth Westar which was in storage on the ground. HCI took control of these satellites in January 1990. Later that year, HCI purchased three more satellites from IBM's Satellite Transponder Leasing Corporation. They are SBS 4 and 5, acquired in orbit, and SBS 6, which was launched later.

The first three Galaxy satellites and the three Westars in orbit all operate in C-band (4 and 6 GHz) and all need to be replaced between 1990 and 1993. The SBS satellites operate in Ku-band (12 and 14 GHz). Only SBS 4 requires replacement in that same period. The replacements are two types of Galaxy satellites. Their numbering relates to the satellites they replace and hence are not in order of their expected launches.

The first set of replacements are Galaxy V, VI, and IR (R for replacement of Galaxy I). Galaxy VI is the renamed Western Union ground spare. These three satellites operate in C-band. The second set of replacements are Galaxy IV, VII, and VIII. These satellites have a completely different design and operate in both C-band and Ku-band.

The C-band Galaxy satellites have the same design as Westar IV and V, a design shared by the satellites of several other systems. All of the satellites have the same body with the cylindrical, deployable solar array and the mirrored thermal radiator band. Also, all have a deployable antenna attached to a despun communications equipment platform on the end opposite the deployable solar array. The satellite is about 7 ft in diameter and only 9 ft in the stowed, launch configuration, but over 22 ft when deployed. The Galaxy V, VI, and IR satellites are taller than the Galaxy I to III satellites; the extra body height allows more surface area for solar cells, to provide more power. The extra power supports higher transmitter power. Galaxy V, VI, and IR also have higher reliability and longer life than the earlier Galaxy satellites. Other details of these satellites (I to III, V, VI, IR) are as follows:

Satellite

Cylinder, 85-in. dia., 21 ft 8 in./24 ft 7 in. (I-III/V, VI, IR) in deployed condition

Approximately 1200/1400 lb (I-III/V, VI, IR) in orbit, beginning of life

Solar cells and NiCd batteries, approximately 990 W beginning of life (I-III)

Spin-stabilized, gyrostabilized, approximately 50 rpm

Solid rocket motor for apogee maneuver, monopropellant liquid propulsion for on-orbit use

Configuration

Twenty-four 36-MHz bandwidth single-conversion repeaters, dual-polarization frequency reuse

Capacity

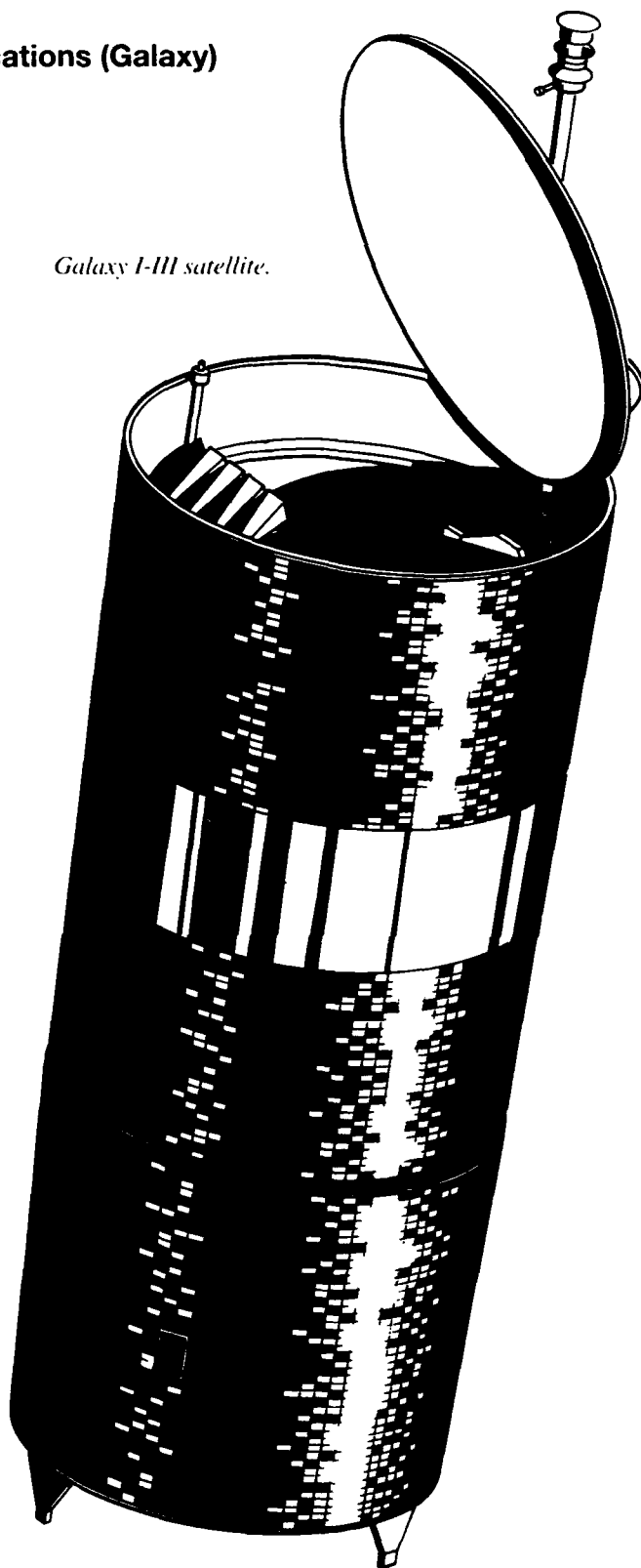
Approximately 1000 voice circuits or one TV signal per repeater

Transmitter

3702 to 4198 MHz

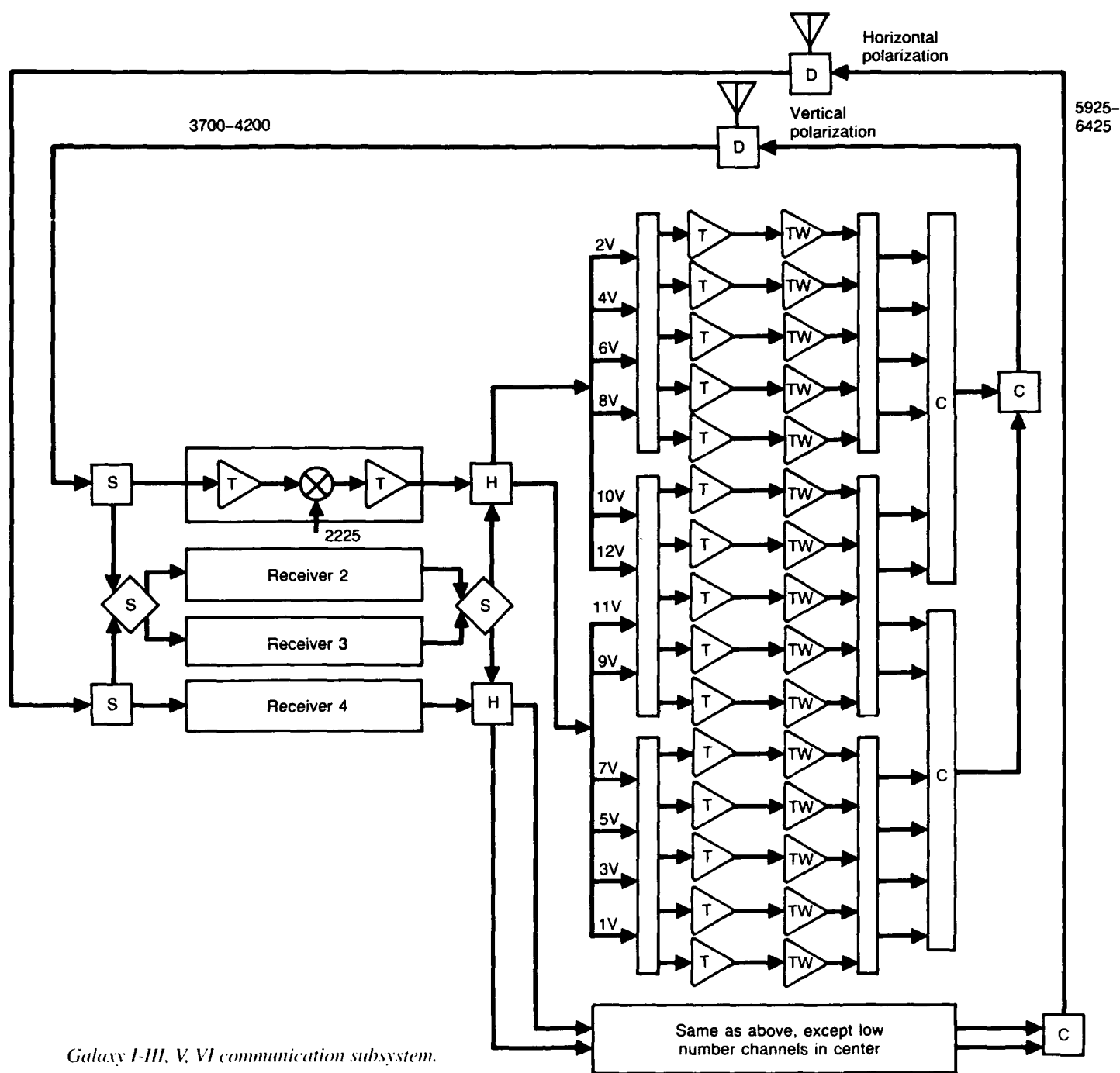
Thirty 9/10-W (I-III/VI) TWTAs arranged in six groups to provide four active and one spare amplifier for every four repeaters

Galaxy I-III satellite.



Thirty 16-W TWTAs (V, IR) to provide twenty-four active and six spares

ERP, minimum over specified area, 33-34/34-35/36-37 dBW (CONUS), 29-30/33/35 dBW (Alaska), 28-29/29/31 dBW (Hawaii), 28-30/29-31/31 dBW (Puerto Rico), for Satellites I, II, III/VI/V, IR



Receiver

5927 to 6423 MHz

Two active plus two spare receivers

G/T, minimum over specified area, -2 to -4 dB/K (CONUS), -5 to -7.5 dB/K (Alaska), -7.5 to -9 dB/K (Hawaii), -6 to -10 dB/K (Puerto Rico)

Antenna

Two 72-in.-diam paraboloids with polarizing grids, one behind the other, each handles one of two orthogonal linear polarizations

Design life

Nine (I-III), ten (VI), and twelve (V, IR) years

Orbit

Synchronous equatorial, stationkeeping to $\pm 0.1^\circ$ N-S and E-W

Orbital history

I: launched 28 June 1983, in use, 134° W longitude

II: launched 22 September 1983, in use, 74° W longitude

III: launched 21 September 1984, in use, 93.5° W longitude

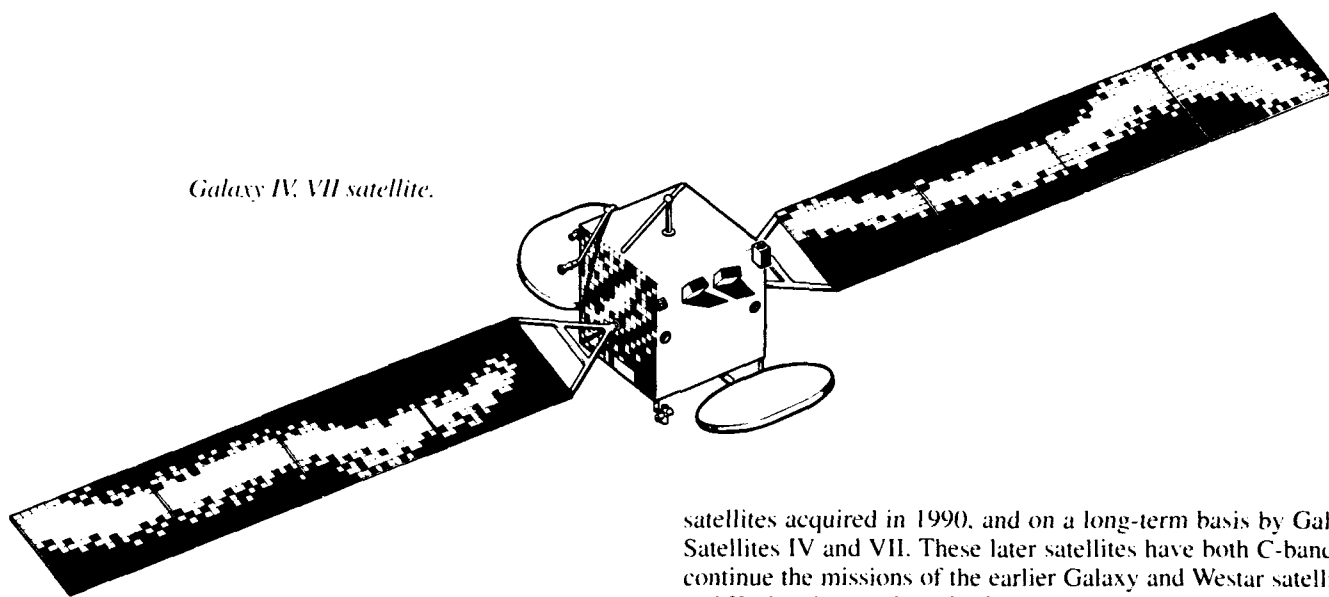
Delta 3920/PAM launch vehicle

VI: launched 12 October 1990, spare, 91° W longitude

Ariane launch vehicle

V: launch scheduled late 1991, will replace Westar V at 122° W longitude

Galaxy IV, VII satellite.



IR: launch scheduled 1992, will replace Galaxy I at 133°W longitude

Atlas II launch vehicle

Management

Developed by Hughes Aircraft Company for Hughes Communications, Inc.

Operated by Hughes Communications, Inc.

The communication subsystem operates in the 4- and 6-GHz bands. It has the common arrangement of twenty-four channels with twelve on each of two orthogonal polarizations. There are four wideband receivers, one for each polarization and two spares. The transmitter has one amplifier per channel with one spare for every four channels.

The first Galaxy satellite was launched in June 1983. Its assigned location provides visibility to all fifty states and Puerto Rico. In 1981, HCI started selling channels on this satellite to distributors of television programming. The sales gave the distributors control over their own satellite resources. In turn, the use of one satellite by so many distributors was an inducement to many cable television system operators to install an antenna to receive the programming available on Galaxy I. At present, about twenty channels are in use with the others as reserves but available for occasional, preemptible uses.

Galaxy II, launched in September 1983, and Galaxy III, launched in September 1984, are located farther east and have poor visibility from Alaska and Hawaii. They are being used primarily for business communications in CONUS, including telephone, data, and video conferencing applications.

The Galaxy satellites are operated from a control center in the HCI facility in Los Angeles. The primary TT&C site is located near New York City. Another site is in Ventura County, about 50 miles north of Los Angeles.

The Westar and SBS satellites purchased by HCI are described in separate prior sections.

In 1983, HCI applied for permission to operate another set of Galaxy satellites in Ku-band. These satellites were proposed to have sixteen channels each, with TWTAs powers of 40 to 50 W per channel. These satellites were authorized in 1985 but never built. Their function was replaced on an interim basis by the SBS

satellites acquired in 1990, and on a long-term basis by Galaxy Satellites IV and VII. These later satellites have both C-band, to continue the missions of the earlier Galaxy and Westar satellites, and Ku-band, to replace the SBS satellites.

Galaxy IV and VII, plus a spare satellite (Galaxy VIII) being built with them, are three-axis-stabilized. They use a new satellite design of Hughes Aircraft, which also is the basis for the Navy's UHF Follow-On and Aussat B. The satellites are larger than the design common to the earlier Galaxy, Westar, and SBS satellites. The larger design allows twice as much communications payload to be carried. This payload makes full use of the allocated frequency bands at both 4/6 GHz and 12/14 GHz. Details of the satellite and payload are as follows:

Satellite

Rectangular body, approximately $6 \times 7 \times 7$ ft. span of solar array—approximately 80 ft

Approximately 3600 lb in orbit, beginning of life

Sun-tracking solar arrays and NiH_2 batteries, approximately 4600 W in orbit, beginning of life

Three-axis-stabilized using gimballed momentum wheels

Unified liquid bipropellant propulsion for apogee maneuver and on-orbit use

Configuration

4/6 GHz: twenty-four 36-MHz bandwidth single-conversion transponders, dual-polarization frequency reuse

12/14 GHz: sixteen 27-MHz bandwidth and eight 54-MHz bandwidth single-conversion transponders, dual-polarization frequency reuse

Transmitter

4/6 GHz: 3702 to 4198 MHz

Thirty 16-W solid-state amplifiers arranged in two groups of fifteen to provide twelve active plus three spare amplifiers

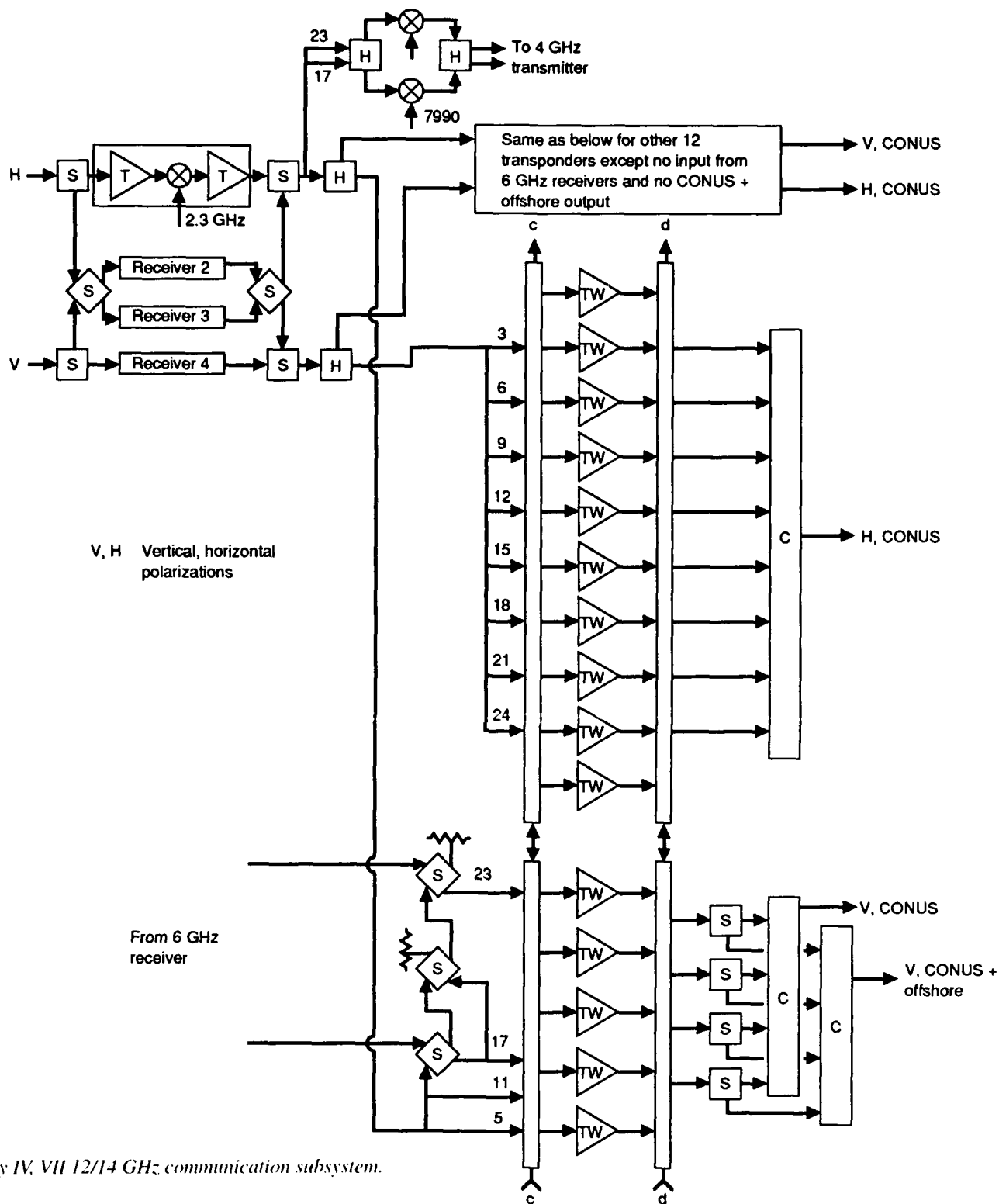
ERP >40 dBW (peak), 37 dBW (most of CONUS), 35 dBW (CONUS minimum), 35 dBW (southeastern Alaska), 32 dBW (Puerto Rico), 31 dBW (Hawaii)

12/14 GHz: 11.706 to 12.197 GHz

Thirty 50-W TWTAs arranged in two groups of fifteen to provide twelve active plus three spare amplifiers

Receiver

4/6 GHz: 5927 to 6423 MHz



Galaxy IV, VII 12/14 GHz communication subsystem.

Two active plus two spare receivers

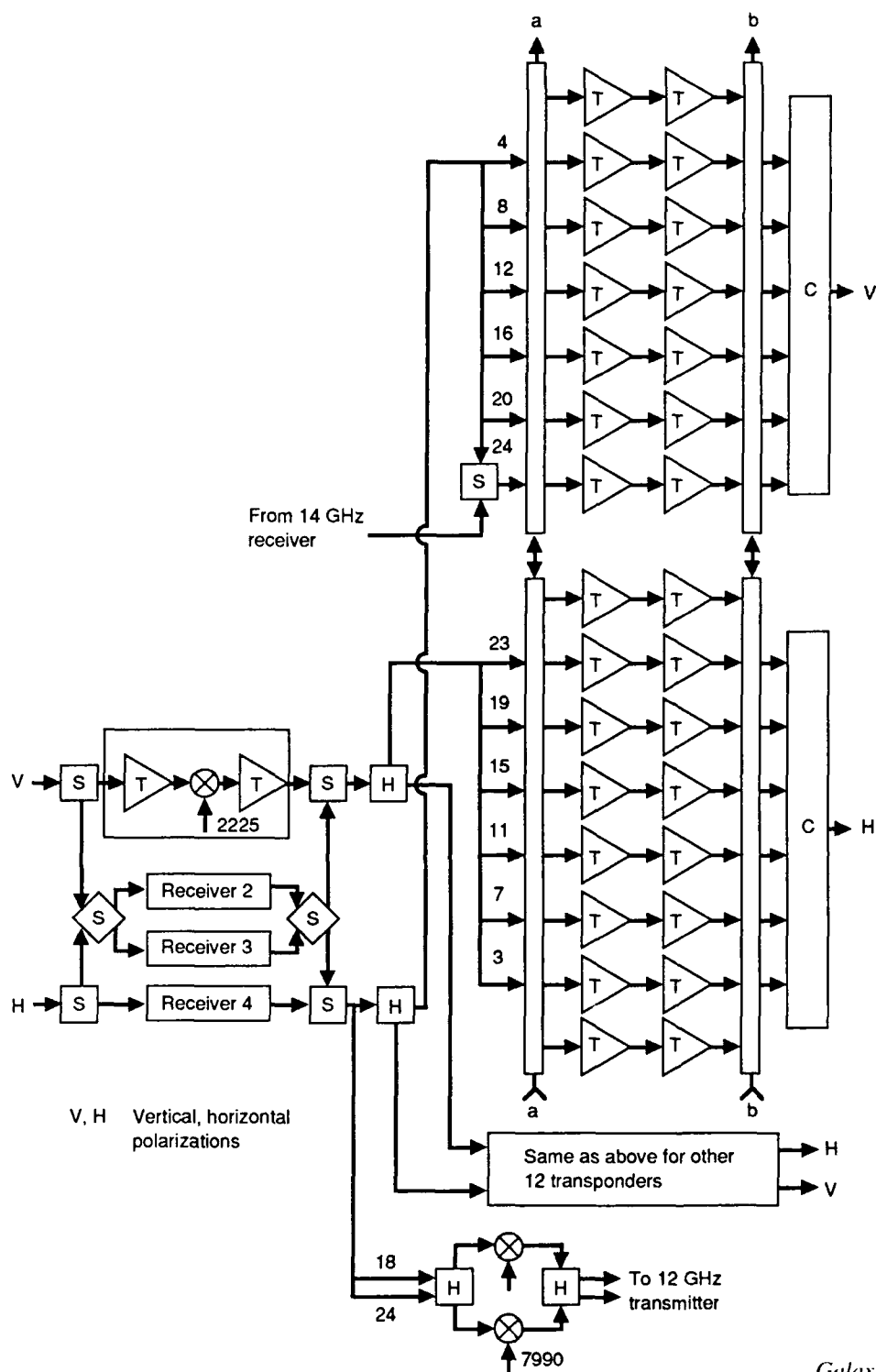
Preamplifier noise figure <2 dB

G/T >+2 dB/K (peak), -1 to -2 dB/K (most of CONUS), -3 to -4 dB/K (CONUS minimum), -4 to -5 dB/K (southeastern Alaska), -6 dB/K (Puerto Rico), -10 dB/K (Hawaii)

12/14 GHz: 14.006 to 14.497 GHz

Two active plus two spare receivers

HEMT preamplifiers, 2-dB noise figure



Galaxy IV, VII 4/6 GHz communication subsystem.

Orbit

Synchronous equatorial

Orbital history

IV: launch planned end of 1992, will go to 99°W longitude

VII: launch planned third quarter 1992, will go to 91°W longitude

Ariane launch vehicle

Management

Developed by Hughes Aircraft Company for Hughes Communications, Inc.

Operated by Hughes Communications, Inc.

The 4/6 GHz communication subsystem is a twenty-four transponder design similar to the earlier Galaxy satellites. Added equipment allows optional upconversion of two transponder passbands for transmission at 12 GHz. The 4/6 GHz antenna pattern

covers all of CONUS with decreasing performance over Alaska and the Caribbean and has a secondary beam for Hawaii.

The 12/14 GHz subsystem has sixteen 27-MHz bandwidth transponders on one polarization and eight 54-MHz transponders on the other polarization. Two of the latter transponders' passbands may be downconverted for transmission at 4 GHz. The receivers' antenna pattern covers CONUS plus surrounding areas. The transmitters' antenna pattern covers only CONUS except for an optional pattern that includes the surrounding areas. Four transponders may be individually switched to this broader coverage.

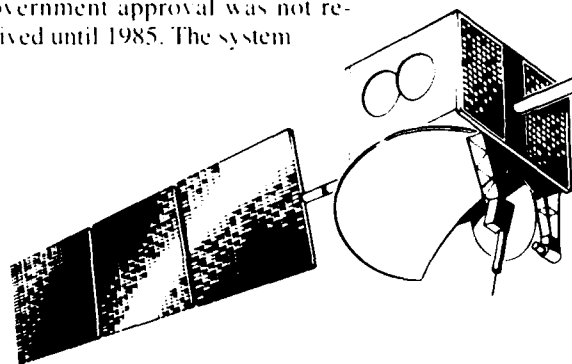
Galaxy IV and VII are in development and will be launched in 1992. Galaxy VIII will remain on the ground as a spare.

* * * * *

1. *Aviation Week & Space Technology* (17 December 1979), p. 62; (15 June 1981), p. 54; (9 May 1983), p. 60; (11 July 1983), p. 53; (25 July 1983), p. 56; (19 December 1983), p. 28; (3 February 1986), p. 42; (24 March 1986), pp. 70, 83.
2. M. B. Worsham and B. R. Elbert, "Operational Aspects of the Westar Acquisition by Hughes Communications," Paper 90-0893, *AIAA 13th Communication Satellite Systems Conference* (March 1990).
3. D. Williams, "HCI Looks Ahead," *Space*, Vol. 6, No. 6 (November-December 1990).

Spacenet

Southern Pacific Communications Company (SPCC) had, for many years, operated a network for dedicated and public long-distance telephone and data links. SPCC owned much of the terrestrial portion of the network but leased all the satellite portion. The company contracted for development of the Spacenet satellites [1-3] to replace the leased satellite capacity starting in 1984. In October 1982, GTE and Southern Pacific agreed that GTE would acquire all the stock of SPCC. Other communications companies objected to the agreement because of the size of the combination both in terrestrial and satellite communications. However, the agreement was completed by September 1983, although government approval was not received until 1985. The system



is now called GTE Spacenet, and the company owns and operates both the Spacenet and GStar satellites.

The Spacenet design is based on, and is very similar in appearance to, the RCA (GE since 1986) satellite design. The satellite is shown here in the deployed condition. The two sun-tracking solar array wings are each composed of three panels, which are folded against the satellite body for launch. The antenna feed horns and reflectors are mounted on the earth-viewing side of the satellite body. The two spheres protruding from the east and west sides of the body are tanks for propellant used for attitude adjustments and stationkeeping maneuvers. The communication subsystem is mounted on the north and south panels of the body. The satellite details are as follows:

Satellite

Rectangular body, 39 × 52 × 64 in., with antennas and feeds fixed on the earth-viewing face, solar panels deployed from north and south faces, span across solar panels 47 ft, height, including antenna feeds about 11 ft

1551 lb in orbit, beginning of life

Spacenet satellite.

Sun-tracking solar array and NiH₂ batteries, approximately 1300 W minimum at end of life

Three-axis stabilization using momentum wheels and magnetic torquers, approximately ±0.2-deg accuracy

Solid rocket motor for apogee maneuver, monopropellant liquid propulsion for on-orbit use

Configuration

4/6 GHz: twelve 36-MHz bandwidth and six 72-MHz bandwidth single-conversion repeaters, dual-polarization frequency reuse

12/14 GHz: six 72-MHz bandwidth repeaters

Capacity

Up to 3600 voice circuits or one TV signal or 60 Mbps per 36-MHz bandwidth (twice as much in 72 MHz)

Transmitter

4/6 GHz: 3702 to 4178 MHz (36-MHz repeaters)

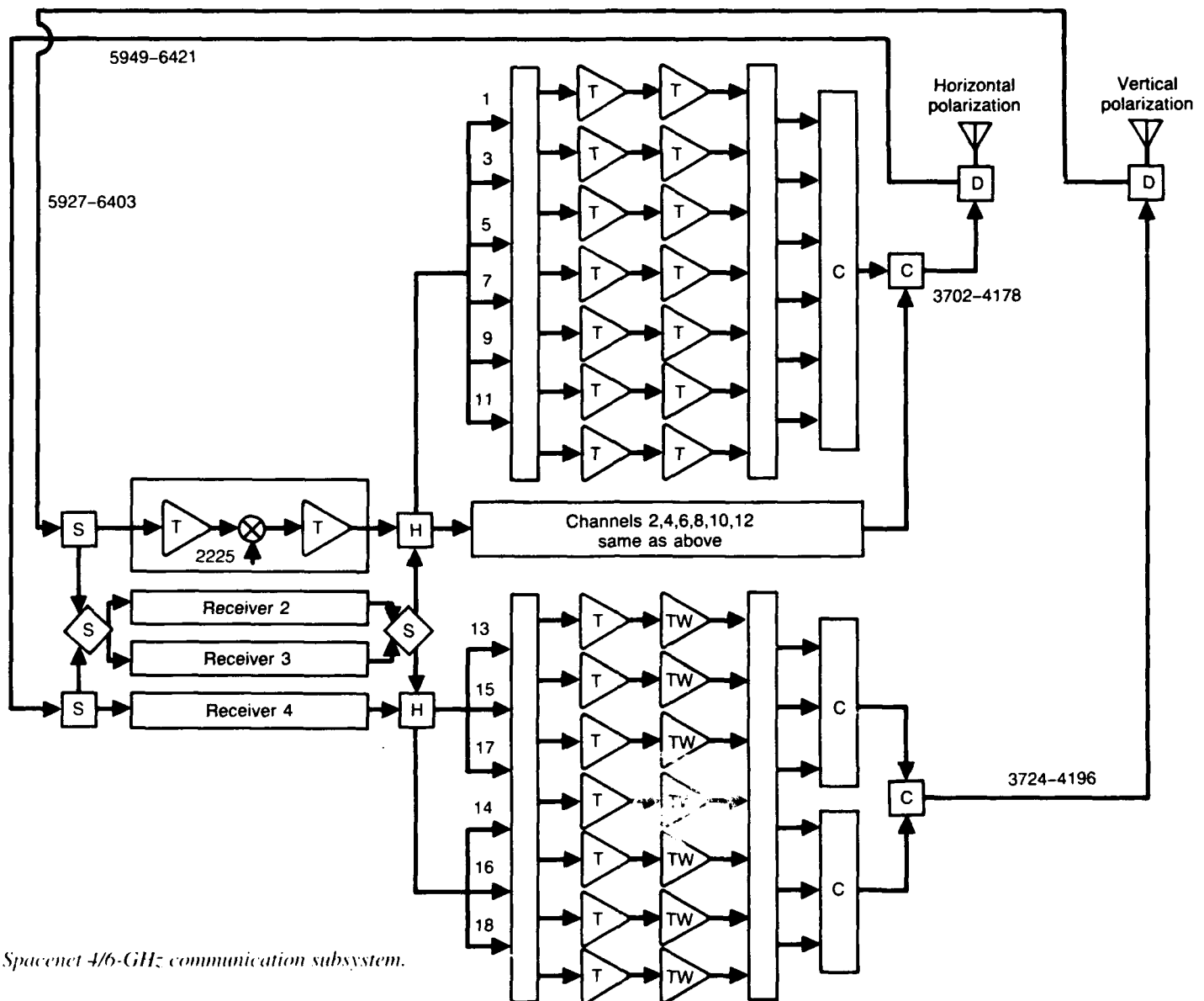
One 8.5-W transistor amplifier per repeater

ERP 34 dBW (CONUS), 28 dBW (Alaska), 25 dBW (Hawaii, Puerto Rico)

3724 to 4196 MHz (72-MHz repeaters)

One 16-W TWT per repeater

ERP 36 dBW (CONUS), 32 dBW (Alaska), 28 dBW (Hawaii, Puerto Rico)



Spacenet 4/6-GHz communication subsystem.

One spare amplifier for every six repeaters
 12/14 GHz: 11.704 to 12.176 GHz
 One 16-W TWT per repeater, 41 dBW ERP (CONUS)
 One spare amplifier for every six repeaters

Receiver

4/6 GHz: two active plus two spare receivers
 5927 to 6403 MHz, (36-MHz repeaters) G/T -5 dB/K (CONUS), -7 to -9 dB/K (Alaska, Hawaii, Puerto Rico)
 5949 to 6421 MHz, (72-MHz repeaters) G/T -2 to -3 dB/K (CONUS), -7 dB/K (Alaska, Hawaii)
 12/14 GHz: one active plus one spare receiver, 14.004 to 14.476 GHz, -3 dB/K G/T (CONUS)

Antenna

4/6 GHz: two paraboloids, approximately 4 x 5 ft, sharing same physical aperture, each with an embedded grid for one of two orthogonal linear polarizations, six feed horns per polarization with coverage for CONUS plus Alaska and Hawaii or CONUS plus Puerto Rico and the Virgin Islands

12/14 GHz: one paraboloid, four feed horns, linear polarization, CONUS coverage

Design life

Ten years

Orbit

Synchronous equatorial, stationkeeping to $\pm 0.05^\circ$ N-S and E-W

Orbital history

1: launched 22 May 1984, in use, 120° W longitude
 2: launched 10 November 1984, in use, 69° W longitude
 3: launch vehicle failure September 1985
 3R: launched 11 March 1988, in use, 87° W longitude
 4: formerly named ASC 2 (see ASC description)
 Ariane launch vehicle

Management

Developed by GE Astro Space (formerly RCA Astro Electronics) for GTE Spacenet Corporation

Operated by GTE Spacenet Corporation

Spacenet 12/14-GHz communication subsystem.

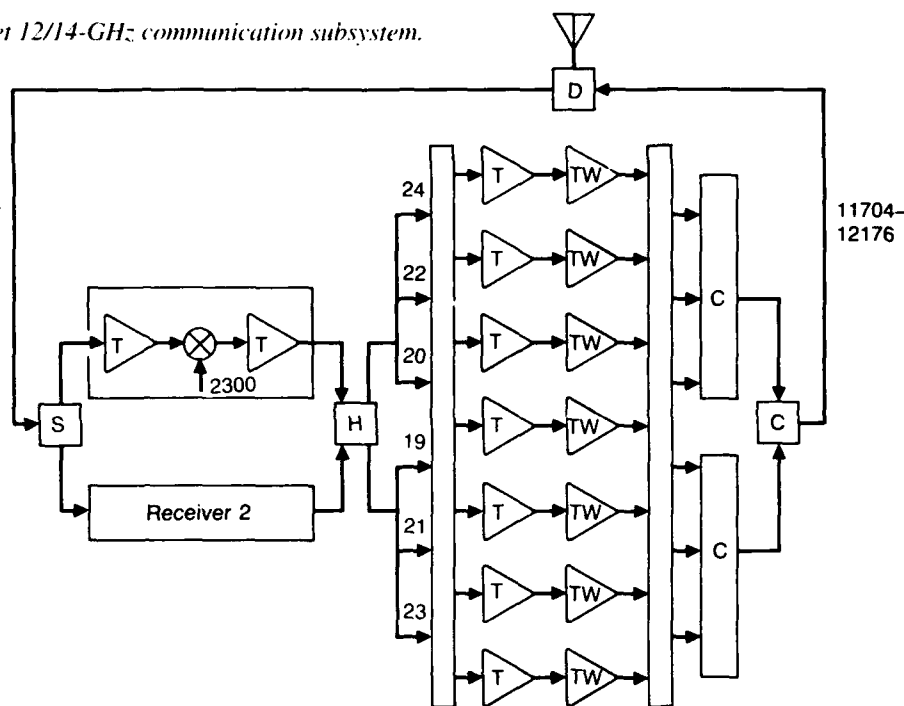
Spacenet is the first United States domestic satellite that operates in both the 4/6-GHz and the 12/14-GHz frequency bands. The satellites in orbit prior to Spacenet all operated in either one or the other of these two bands. The primary objective in the communication subsystem design was to maximize bandwidth subject to launch vehicle-imposed weight constraints. The result is a twenty-four-channel design with 50% more bandwidth than a contemporaneous twenty-four-channel 4/6-GHz design.

The 4/6-GHz portion of the communication subsystem has two sections. One is a typical set of twelve 36-MHz bandwidth repeaters. The other section, which uses the orthogonal antenna polarization, has six 72-MHz bandwidth repeaters. The weight saved, relative to a twelve-repeater design, allows an additional six repeaters of 72-MHz bandwidth. These six operate in the 12/14-GHz band. The narrowband (36 MHz) repeaters use solid-state amplifiers.

The wideband repeaters use TWTs with twice the output power. The 4/6-GHz antenna patterns are adjusted to the expected satellite location. The western satellite pattern covers all fifty states, whereas the eastern satellite pattern covers CONUS and the Caribbean. The 12/14-GHz pattern is optimized for CONUS coverage, with some degradation in parts of Texas, Florida, and Maine.

Two Spacenets were launched in 1984. The third satellite was lost in a launch vehicle failure in 1985. A replacement was launched in 1988. The first was stationed in a westerly location, and the 4/6-GHz channels are used mostly for distribution of television programs and also for voice and data service requiring its coverage of Alaska and Hawaii. The second satellite is primarily devoted to business communications. Types of traffic include voice, data, facsimile, and video conferencing. The GTE long-distance network, called GTE Sprint, is making use of all three types of transponders on Spacenet. Earth stations are located near

14004-
14476



at least eleven metropolitan areas. Transmissions are QPSK/TDMA. Both digital speech interpolation and adaptive voice coding are used to achieve a capacity of 3600 voice circuits per 36-MHz bandwidth.

The control center for the Spacenet satellites is in McLean, Virginia, near Washington, D.C. The TT&C sites are located in Woodbine, Maryland and San Ramon, California.

1. C. J. Waylan, "The Spacenet Satellites," Paper 82-0520, *AIAA 9th Communications Satellite Systems Conference* (March 1982).
2. A. Jacobs and B. Pourmand, "A Digital Satellite Communications System for Sprint," Paper 84-0717, *AIAA 10th Communication Satellite Systems Conference* (March 1984).
3. *Aviation Week & Space Technology* (31 March 1980), p. 26; (21 December 1981), p. 12; (25 October 1982), p. 58; (23 September 1985), p. 22; (24 March 1986), p. 83.

GStar

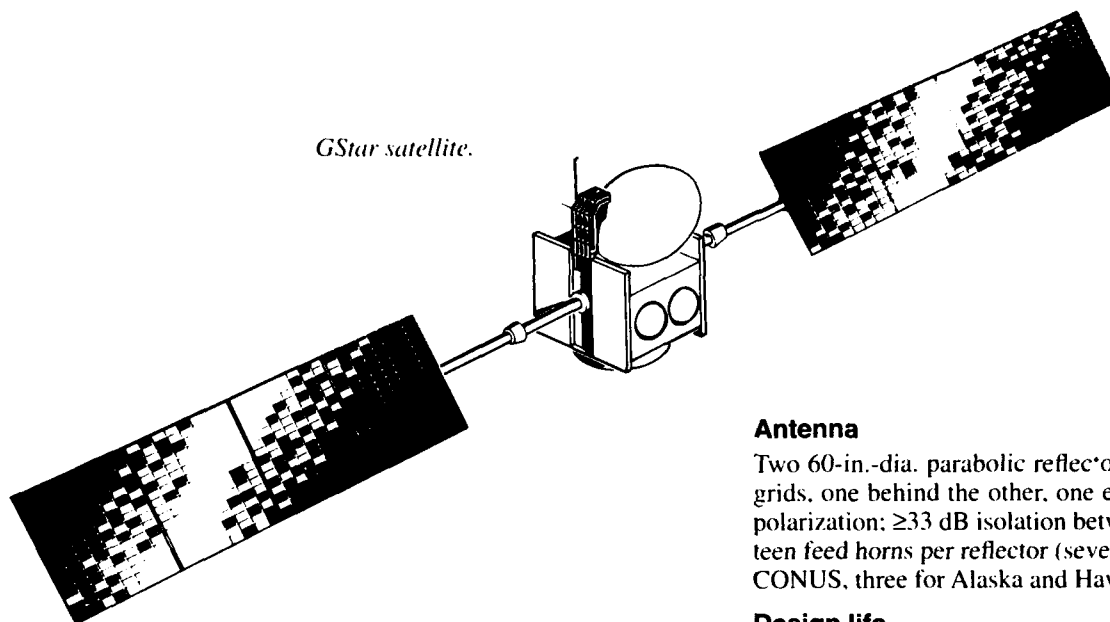
GTE Spacenet Corporation, formerly GTE Satellite Corporation, is the owner of the GStar satellites [1-6]. Like the Spacenet satellites, the GStars have a design based on the RCA (GE since 1986) satellites. They have a central box-like body structure from which the two sun-tracking solar arrays are deployed. The antenna structure is fixed on the earth-viewing side of the body. All other equipment is mounted within or on the surface of the body. The satellite has nickel-hydrogen batteries and electrothermal hydrazine thrusters, both of which were new technology items not common in communication satellites in 1985. Both contribute to increased life for a given satellite weight.

The GStar communication subsystem uses the 12- and 14-GHz bands. The subsystem has sixteen channels, each with a 54-MHz bandwidth, and uses dual-polarization frequency reuse. The

receive antenna provides CONUS coverage on one polarization and a combined coverage for CONUS, Alaska, and Hawaii on the other. The transmit antenna has four beams. Channels 1 and 3 are permanently connected to a combined coverage beam. Each of the other fourteen channels has a variable power divider. These dividers can route the power to either a west beam or an east beam or split the power between the two to form a CONUS beam. The west and east coverages correspond to the parts of CONUS west and east of the Mississippi River.

Channels 1 and 3 have 30-W TWTs, and all other channels have 20-W TWTs. The power radiated by the satellite is sufficient to support 60-Mbps transmissions in the CONUS and combined beams, or 90 Mbps in the west and east beams. A total of 20 TWTs are available in a ring redundancy arrangement, three of

GStar satellite.



which are the 30-W type. The GStar receivers have a parametric amplifier for the first stage and an FET amplifier for the second stage, followed by down conversion and additional amplification. Performance values and other satellite details are as follows:

Satellite

Box, 6 × 6 × 8 ft with antennas fixed on earth-viewing side and solar arrays deployed from two sides, overall span approximately 55 ft, overall height approximately 11 ft

Approximately 1400 lb in orbit, beginning of life

Sun-tracking solar array and NiH₂ batteries, 1700–1900 W beginning of life, 1330 W minimum after ten years

Three-axis stabilization using momentum wheels and magnetic torquers; accuracy ±0.04 deg (pitch), ±0.05 deg (roll), ±0.13 deg (yaw)

Solid rocket motor for apogee maneuver, monopropellant liquid propulsion for on-orbit use

Configuration

Sixteen 54-MHz bandwidth single-conversion repeaters, dual-polarization frequency reuse

Capacity

Up to 5400 voice circuits or 90 Mbps per repeater

Transmitter

11.703 to 12.198 GHz

Three 30-W TWTs for two repeaters, seventeen 20-W TWTs for fourteen repeaters

ERP: (30-W repeaters) ≥40 dBW for CONUS, Alaska, Hawaii, up to 45 dBW in parts of CONUS; (20-W repeaters) 40 to 45 dBW over CONUS or approximately 45 dBW over most of eastern CONUS in east spot mode or 42 to 45 dBW over western CONUS in west spot mode

Receiver

14.003 to 14.498 GHz

Two active plus two spare receivers

G/T: ≥−1.5 dB/K over almost all of CONUS, +1 to +4 dB/K in much of CONUS, ≥−3.5 dB/K Alaska and Hawaii

Antenna

Two 60-in.-dia. parabolic reflectors with embedded polarization grids, one behind the other, one each for vertical and horizontal polarization; ≥33 dB isolation between the two polarizations; sixteen feed horns per reflector (seven for west CONUS, six for east CONUS, three for Alaska and Hawaii)

Design life

Ten years

Orbit

Synchronous equatorial, stationkeeping to ±0.05°N-S and E-W, except for GStar 3

Orbital history

1: launched 8 May 1985, in use, 103°W longitude

2: launched 28 March 1986, in use, 105°W longitude

3: launched 8 September 1988, problems during apogee motor firing left satellite in wrong orbit, orbit raised during 1989, began operations November 1989, in use, 93°W longitude

4: launched 20 November 1990, in use, 125°W longitude

Ariane launch vehicle

Management

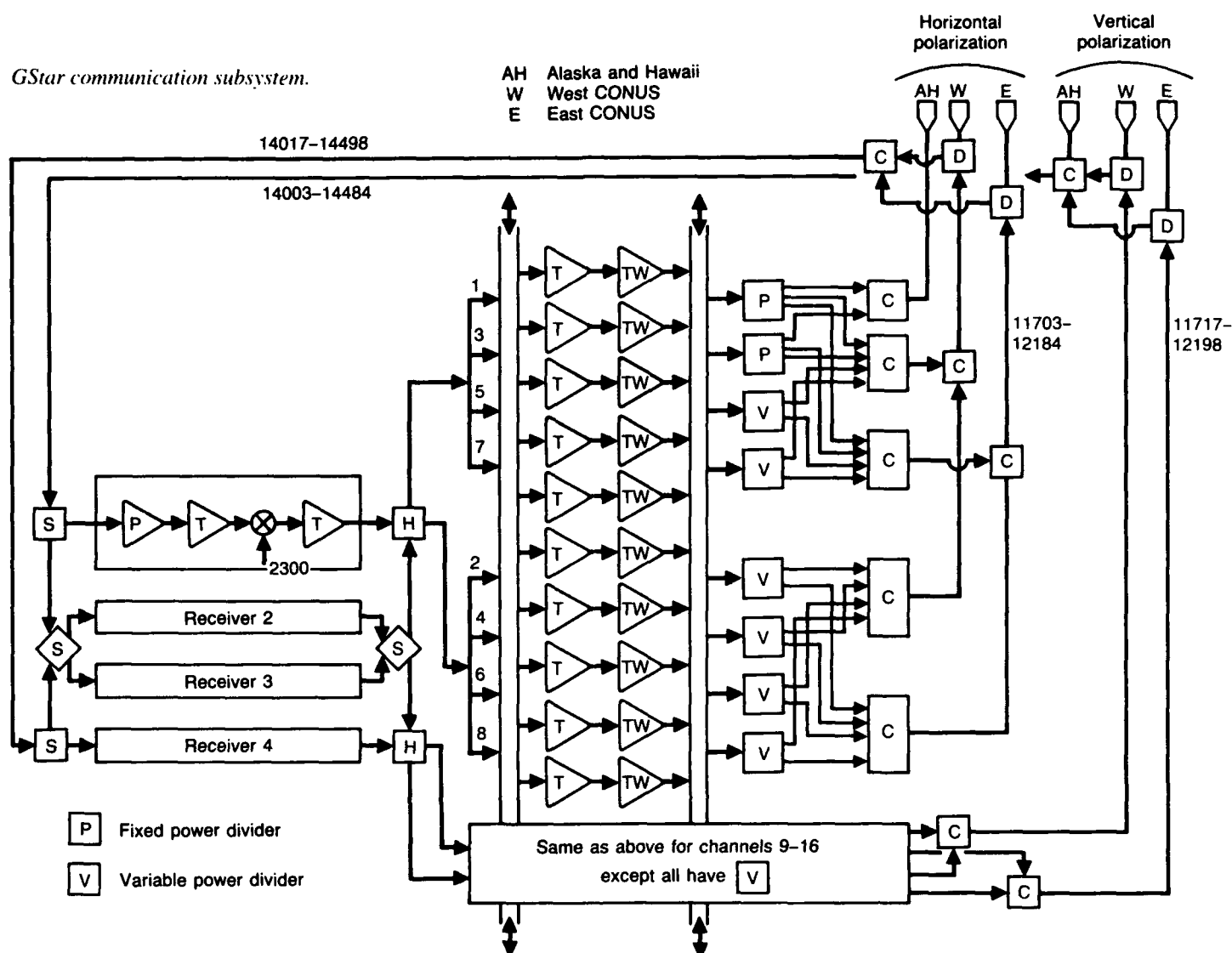
Developed by GE Astro Space (formerly RCA Astro Electronics) for GTE Spacenet Corporation

Operated by GTE Spacenet Corporation

The first two GStar launches were in May 1985 and March 1986. The third launch was in September 1988. When the apogee motor fired, the satellite was not stable, and the orbit perigee was raised by less than half of the expected distance. The cause of the instability was later determined to be due to unbalanced loading of the hydrazine propellant tanks. Beginning in January 1989, the on-orbit propulsion subsystem was used to raise the perigee. The process was very slow because of the low thrust. Nine months later, the satellite was in synchronous orbit, and operational use began in November 1989. Because of the propellant use, the estimated satellite life has been reduced to four or five years, and no north-south stationkeeping is being done. As a result, the satellite orbital inclination was 2 deg when it reached synchronous orbit and is increasing by about 0.75 deg per year. The fourth GStar was launched successfully in November 1990.

The primary traffic on all the satellites is customized digital networks. Each network serves a specific user; in most cases, the ground terminals are located at the user's facilities. Each network can have demand-assignment equipment to increase efficiency. The type of information to be transmitted is not constrained. User equipment can combine voice, data, facsimile, and video inputs to

GStar communication subsystem.



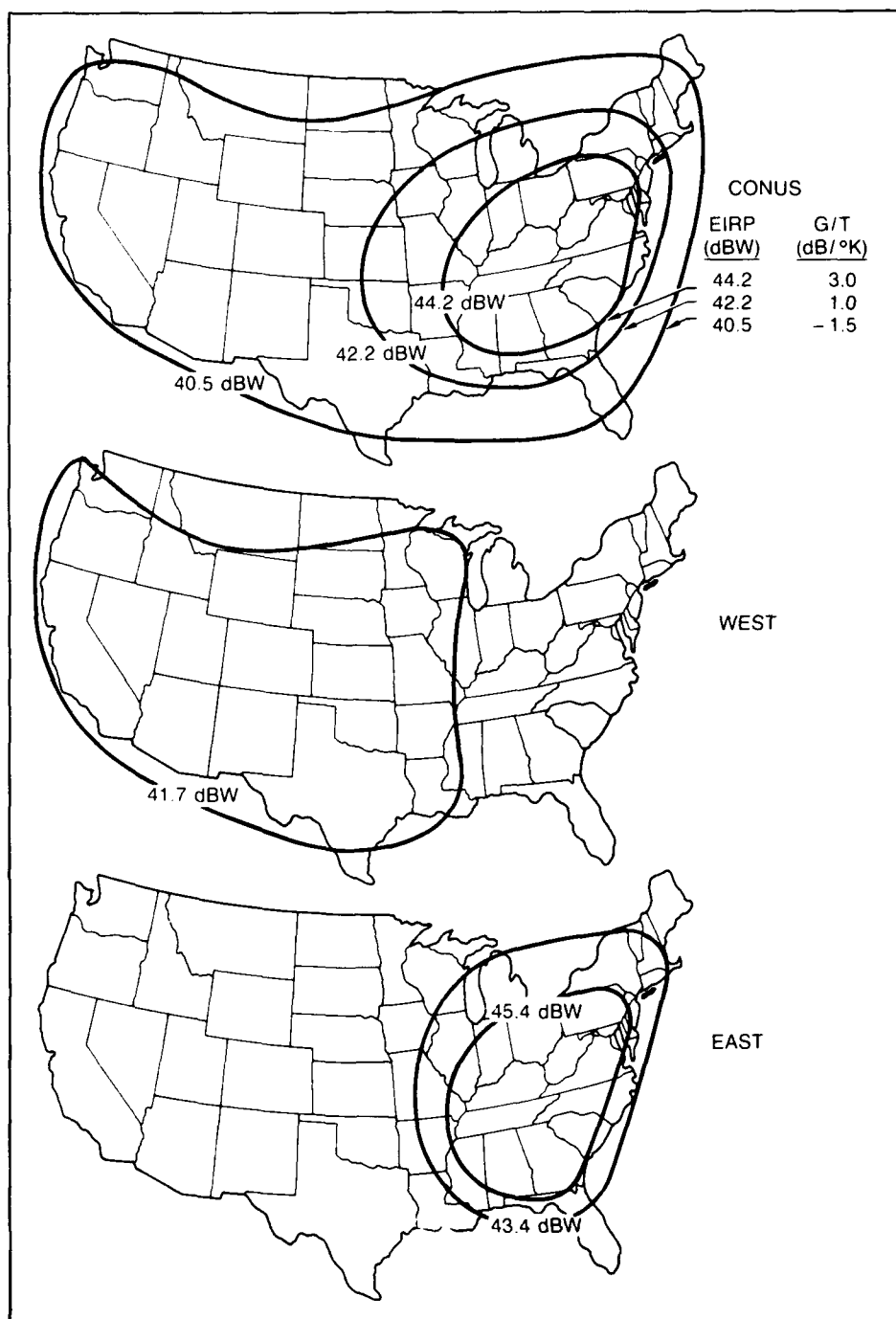
form the transmitted data stream. Data rates vary with user requirements; the maximum network rates are 60 and 90 Mbps with TDMA.

Typical ground terminals for the 60 Mbps networks have 18- to 25-ft-diameter antennas and 500-W output power. For the 90-Mbps networks, the antenna diameter will be 25 to 30 ft and the power 1000 W. Specific antenna sizes will depend on the location, because rain attenuation and satellite performance vary with location. Active uplink power control may be used in locations with high rain attenuation.

The GStar satellite control center is located with the Spacenet control center in McLean, Virginia. The TT&C sites are located in Oxford, Connecticut and Grand Junction, Colorado.

1. D. L. Doan, et al, "Anik D, Brasilsat and GStar Shaped Beam Antennas," Paper 29.5, *First Canadian Domestic and International Satellite Communication Conference* (June 1983).

2. J. Napoli, "GStar - A High Performance Ku-Band Satellite for the 1980s," *AIAA 9th Communications Satellite Systems Conference* (March 1982).
3. M. Louie and J. F. Bottomley, "The GStar 60 MB/s and 90 MB/s Services," Paper 82-0493, *AIAA 9th Communications Satellite Systems Conference* (March 1982).
4. W. Yung and M. Louie, "Acquisition and Synchronization for the GStar TDMA Digital Satellite System," Paper 82-0512, *AIAA 9th Communications Satellite Systems Conference* (March 1982).
5. *Aviation Week & Space Technology* (28 April 1980), p. 22; (17 August 1981), p. 26; (28 September 1981), p. 45; (19 October 1981), p. 19; (30 November 1981), p. 20; (25 October 1982), p. 58; (23 September 1985), p. 22; (24 March 1986), p. 83; (19 September 1988), p. 18; (17 October 1988), p. 23; (24 October 1988), p. 11; (27 March 1989), p. 13.
6. B. Bennett, "The Recovery of GStar III," *Satellite Communications* (June 1991)



GStar beam patterns.

American Satellite Corporation

American Satellite Corporation (ASC) [1-12] was formed in 1972 as a subsidiary of Fairchild Industries and began providing communications services in 1974, using satellite capacity leased from Western Union. In 1979, it became a joint venture of Fairchild and Continental Telephone (later Continental Telecom, now Contel). In 1980, ASC converted its lease to a 20% ownership of the Western Union satellites. To allow for further growth, in March 1983, ASC signed a contract for the development of its own satellites. In 1985, Fairchild sold its interest in ASC to Continental Telecom, which became the sole owner of ASC. In 1987, its name was modified to Contel ASC.

The ASC satellite, a derivative of the RCA satellite, is almost identical to the Spacenet satellite. It is a body-stabilized type that has a box-shaped body with solar arrays deployed from its north and south sides. The communications antennas are fixed on the earth-facing side of the body. An unusual feature is that the satellite has an encrypted command link. The satellite also uses the relatively new (in 1983) nickel-hydrogen battery and electrothermal thruster technologies. The communications subsystem, like Spacenet, has twenty-four channels; twelve are 36-MHz bandwidth and share the lower half of the 4- and 6-GHz bands by means of dual-polarization frequency reuse. The upper half of the

same bands are used by six 72-MHz bandwidth channels also by means of dual polarization. In the 12- and 14-GHz bands, six 72-MHz bandwidth channels use a single polarization. (Launch weight limits preclude additional channels on the orthogonal polarization.) The 36-MHz channels use transistor power amplifiers; the others use TWTs. The subsystem configuration is similar to that of Spacenet. Additional satellite details are as follows:

Satellite

Box, about 5 ft on a side, with antennas and feed fixed on the earth-viewing face, solar panels deployed from north and south faces, span across solar panels about 48 ft, height including antenna feeds about 11 ft

1467 lb in orbit, beginning of life

Sun-tracking solar array and NiH_2 batteries, 1215 W minimum after ten years

Three-axis stabilization using momentum wheels and magnetic torquers, approximately ± 0.2 -deg accuracy

Solid rocket motor for apogee maneuver, monopropellant liquid propulsion for on-orbit use

Configuration

4/6 GHz: twelve 36-MHz bandwidth and six 72-MHz bandwidth single-conversion repeaters, dual-polarization frequency reuse

12/14 GHz: six 72-MHz bandwidth repeaters

Capacity

64 Mbps or approximately 1000 voice circuits or one TV signal per 36-MHz bandwidth

Transmitter

4/6 GHz: 3700 to 3960 MHz (36-MHz repeaters)

One 8.5-W transistor amplifier per repeater

ERP approximately 34 dBW (CONUS), approximately 28 dBW (Alaska), approximately 25 dBW (Hawaii, Puerto Rico)

3940 to 4200 MHz (72-MHz repeaters)

One 16.6-W TWT per repeater

ERP approximately 36 dBW (CONUS), approximately 32 dBW (Alaska), approximately 28 dBW (Hawaii, Puerto Rico)

12/14 GHz: 11.704 to 12.176 GHz

One 17-W TWT per repeater, approximately 41-dBW ERP (CONUS)

One spare amplifier for every six repeaters

Receiver

4/6 GHz: two active plus two spare receivers

5925 to 6185 MHz, (36-MHz repeaters) approximate G/T -5 dB/K (CONUS), -7 to -9 dB/K (Alaska, Hawaii, Puerto Rico)

6165 to 6425 MHz, (72-MHz repeaters) G/T -2 to -3 dB/K (CONUS), -7 dB/K (Alaska, Hawaii)

12/14 GHz: 14.004 to 14.476 GHz, one active plus one spare receiver, -3 dB/K G/T (CONUS)

Antenna

4/6 GHz: two paraboloids, approximately 4 x 5 ft, sharing the same physical aperture, each with an embedded grid for one of two orthogonal linear polarizations

12/14 GHz: one paraboloid, linear polarization

Design life

Ten years (8.5 years nominal fuel load)

Orbit

Synchronous equatorial, stationkeeping to $\pm 0.05^\circ$ N-S and E-W

Orbital history

1: launched 27 August 1985 (deployed from Shuttle 27 August), in use, 127°W longitude

2: launched 12 April 1991, 101°W longitude, name changed to Spacenet 4

3: launch schedule uncertain

Shuttle launch vehicle (1), Delta (2)

Management

Developed by RCA Astro Electronics for American Satellite Corporation

Operated by American Satellite Corporation

The first ASC satellite was launched in August 1985. ASC is using both this satellite and its share in the Westar satellites. The second and third satellites were scheduled for launch in 1986 and 1987. However, that plan was disrupted by the multiple launch vehicle failures in the early part of 1986. ASC 2 was not launched until April 1991. The month before, GTE and Contel completed a merger which includes the GTE Spacenet and Contel ASC satellite systems. As a result, ASC 2 is being renamed Spacenet 4. Consolidation of the Spacenet and Contel ASC ground control facilities and operations will take place over an extended period.

The ASC ground terminals are grouped by the services they support: public commercial, dedicated commercial, and dedicated government. In 1974, ASC started with three public and three government terminals. At the end of 1978, twenty-three terminals were in operation. By 1983, the number increased to about 130 terminals. The public terminals have 33-ft antennas. Dedicated commercial terminal antenna sizes vary from 10 to 33 ft—16 ft and 23 ft are the most common. Error correction coding is used on most links, and encryption is an option used on some links.

Dedicated commercial terminals are located at customer sites to provide private communication networks. More than seventy terminals are in use. Types of information transmitted on these networks include voice, single and multiple data links at 9.6 or 56 kbps, facsimile, and video conferencing. Transmissions are all digital with either FDMA, SCPC, or TDMA operation.

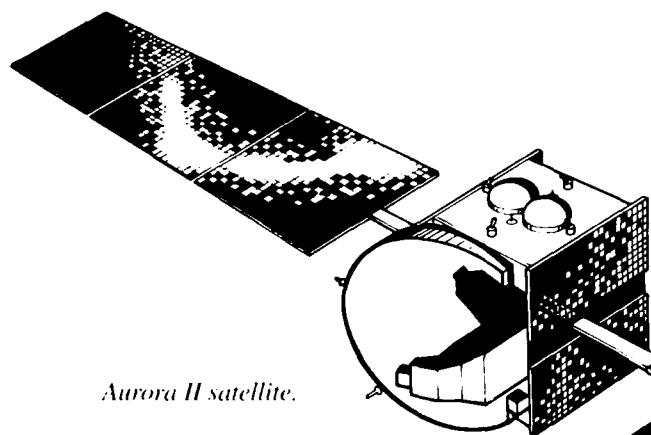
Approximately 50 dedicated government terminals serve NASA, the Department of Defense, and the Department of Energy. Transmissions are digital with bit rates ranging from 56 kbps to 3 Mbps. Examples of traffic include data for the Shuttle and Defense Meteorological Satellite Programs and twenty-four voice circuit trunks.

* * * * *

1. J. G. Puente, "Designing the American Satellite Corporation System," *EASCON '73 Conference Record* (September 1973).
2. S. Ashton and D. Silverman, "The American Satellite Communication System," Paper 74-482, *AIAA 5th Communications Satellite Systems Conference* (April 1974).
3. L. Kilty, "American Satellite Builds a Major Network for Government Users," *EASCON '75 Conference Record* (September 1975).
4. E. Cacciamani, "New Developments in Small Digital Earth Stations," *Pacific Telecommunications Conference* (January 1979).

5. E. Cacciamani and W. Garner, "The American Satellite Digital Communications Network," Paper 49.3, *International Conference on Communications: ICC '79* (June 1979).
6. S. Mittal, E. R. Cacciamani, and J. Hangen, "Use of TDMA in a Domestic Satellite Communications System," *EASCON '79 Conference Record* (September 1979).
7. T. D. Breeden and E. J. Habib, "The Digital Network of American Satellite Corporation," Paper 80-0517, *AIAA 8th Communications Satellite Systems Conference* (April 1980).
8. E. J. Habib and S. Mittal, "A New Integrated Service for American Satellite Network," Paper 82-0617, *AIAA 9th Communications Satellite Systems Conference* (March 1982).
9. I. L. Lebow, "An Integrated Communications Controller for Demand-Assignment," Paper D1.2, *International Conference on Communications: ICC '83* (June 1983).
10. *Aviation Week & Space Technology* (19 August 1985), p. 22; (24 March 1986), p. 83.
11. S. Mittal and W. Garner, "A Specialized TDMA Network for Business Services," *Sixth International Conference on Digital Satellite Communications* (September 1983).
12. O. W. Hoernig, Jr. and D. R. Sood, "Security Enhancement for Commercial Communication Satellite Systems," Paper 15.1, *Military Communications Conference: Milcom '84* (October 1984).

Alascom



Aurora II satellite.

The terminals with 15-ft antennas are equipped for one to eight voice channels. The majority are for public use, but a few are for private lines for specific customers. These transmissions are mostly SCPC/FM. Larger terminals service towns requiring more than eight voice channels and have larger antennas. Transmission formats are SCPC/FM, FDM/FM, and QPSK. The largest terminals are the four gateways, located in the principal Alaskan cities. They handle all communications with other states, serving as intermediate nodes on double hop links between the smaller terminals and other states.

Prior to 1971, the Air Force provided all long-distance communications in Alaska and between Alaska and other states. In that year, the military communications system in Alaska was sold to RCA. One of the terms of the sale was that RCA accept the responsibility for improving long-distance communications in Alaska. RCA established the RCA Alascom [1-6] subsidiary to carry out this task. The size, large undeveloped regions, weather, and population distribution of Alaska all complicate the provision of adequate communications. Only a few cities had good internal communications. The problem facing Alascom was communications between the cities and over 200 small towns and villages, between the towns and villages, and between Alaska and the rest of the United States.

Alascom initially tried VHF links to improve service, but the results were not very good. In 1975, 100 earth terminals were installed in villages to provide two voice circuits each. One was for public telephone calls and the other for health care consultations with urban medical centers. The next year, television reception capability was added to these terminals. Two television programs were broadcast to them—one educational and one entertainment. These programs were received from the satellite and then re-broadcast to the local area by low-power conventional television transmitters. By 1983, the number of terminals had increased to about 200, and by 1989 to over 220, so that every community in the state, with a population of at least 20, was equipped. Most terminals have 15-ft antennas, although about 30 have 33-ft or larger antennas.

Alascom provided the telephone and television services as part of the total RCA satellite communications program using RCA satellites. In 1979, Alascom was sold to Pacific Power and Light Company and renamed Alascom, Inc. It continued to obtain satellite capacity from RCA and bought a satellite from RCA prior to its launch. The antenna pattern of this satellite, RCA 5, was modified to improve coverage of Alaska. It was launched in October 1982 and is in use by Alascom. It is operated by RCA Americom under contract to Alascom. The satellite was named Aurora in 1983; the name was selected in a state-wide contest. Under the RCA-Alascom contract, RCA satellites provide in-orbit backup for Aurora.

In 1986, RCA was bought by GE, and RCA Americom became GE Americom. The cooperation between Alascom and Americom continued through the name change. Plans were developed for an Aurora II satellite to replace the first Aurora

(or Aurora I). The second satellite has the same basic design as the first. It has increased transmitter power and redundancy, and spacecraft improvements to increase reliability and extend the life. Aurora II also has a secure command link.

Aurora satellites have two antenna beam patterns. One covers Alaska, the other Alaska plus CONUS with a lower power level on Hawaii. The broader coverage is used for all uplinks. On Aurora I, twelve transponders are connected to the Alaska beam for downlinks and twelve to the broader beam. On Aurora II, the corresponding numbers are six and twelve, with another six transponders individually switchable between the two beams. The Alaska beam is used for intrastate communications. The other beam is used for communications between Alaska and other states; capacity not required by Alascom is used by Americom as part of its national satellite network.

Details of the two satellites are listed and apply to both, unless specified by (I) or (II).

Satellite

Body 56 × 64 × 69 in., solar array span 47 ft

1320/1420 lb (I/II) in orbit, beginning of life

Sun-tracking solar array, NiCd/NiH₂ batteries (I/II), 980 W after ten years (I), >1000 W after twelve years (II)

Three-axis stabilization using momentum wheels and magnetic torquers, ±0.15-deg antenna pointing

Solid rocket motor for apogee maneuver, liquid hydrazine propulsion for on-orbit use

Configuration

Twenty-four 36-MHz bandwidth single-conversion transponders, dual-polarization frequency reuse

Transmitter

3702 to 4198 MHz

One 8.5/11-W solid-state amplifier per transponder plus one/two spares per six transponders (I/II)

ERP 37 to 38 dBW for Alaska, 33 to 34 dBW for Alaska and CONUS combined, with 26 to 28 dBW for Hawaii

Receiver

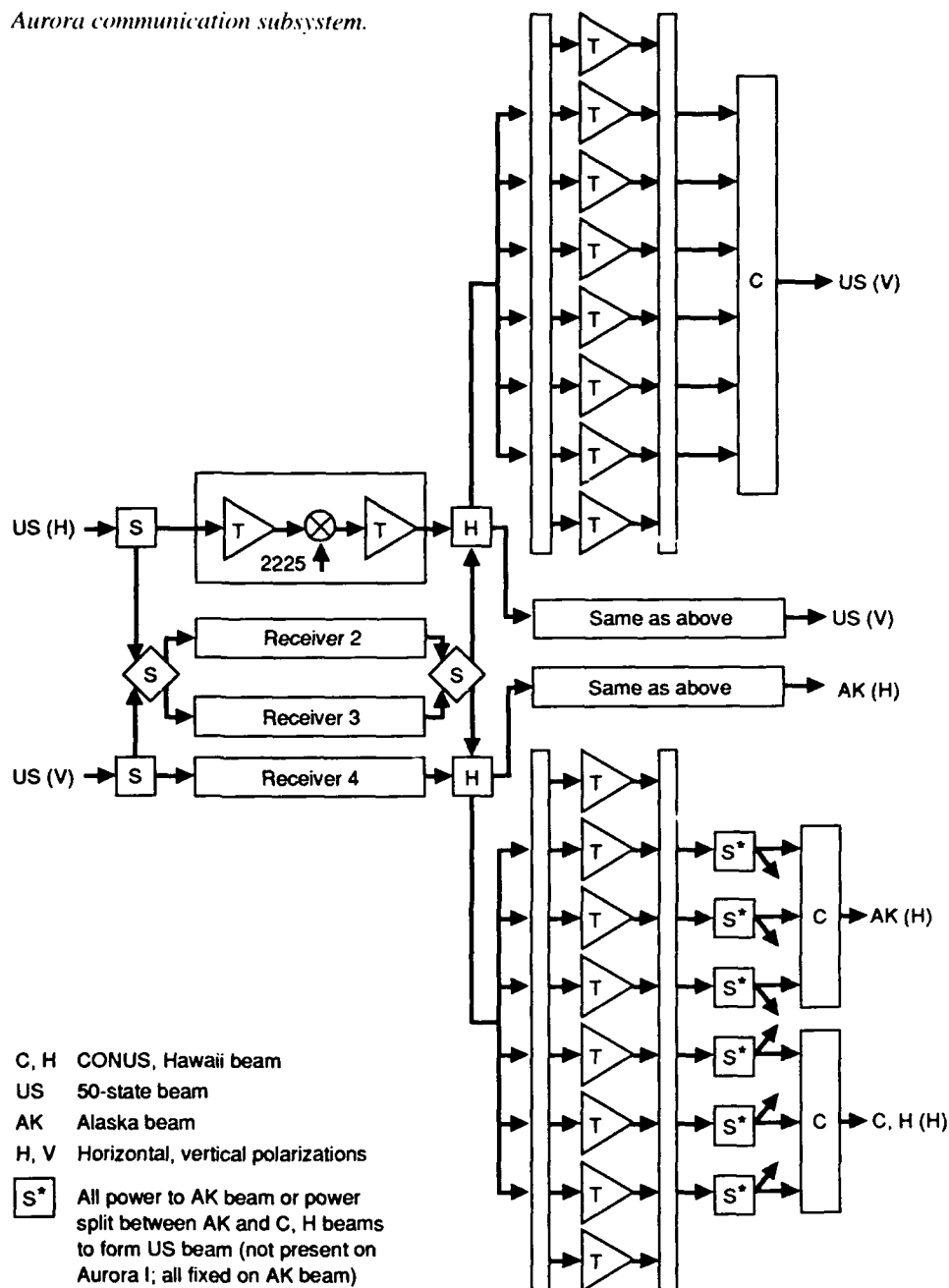
5927 to 6423 MHz

Two active plus two spare receivers

FET preamplifiers

G/T -3 dB Alaska and CONUS combined

Aurora communication subsystem.



Antenna

One dual-gridded offset-fed antenna with one feed array of six or seven horns for each polarization, 7-ft reflector diameter, dual linear polarizations, 33 dB isolation between the polarizations

Design life

Ten/twelve years (I/II)

Orbit

Synchronous equatorial, stationkeeping to ±0.1°N-S and E-W

Orbital history

I (also known as RCA 5): launched 28 October 1982, in use until Spring 1991

Delta 3924 launch vehicle

II: launched 29 May 1991, in use, 139°W longitude
Delta 7925 launch vehicle

Management

Developed for Alascom and GE (formerly RCA) Americom by
GE Astro Space (formerly RCA Astro Electronics)

Operated by GE Americom

Aurora I was launched in 1982 and was in use until the spring of 1991. Then, a low propellant level caused problems and required the transfer of all traffic to GE Satcom C-1. The traffic was moved to Aurora II in August 1991 following its May launch.

* * * * *

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MARISAT

Marisat [1-27] was developed to provide communications between ships and shore stations. During its first years of operation, the primary user was the Navy, for whom it filled part of the gap between the end of Tacsat and LES 6 operations and the beginning of FLTSATCOM operations. For this reason, the satellite is sometimes called Gapsat or Gapfiller. This service is described in the section on military satellites. Marisat also provides service for commercial shippers.

Marisat is a derivative of the Anik A satellite. The basic structure and support subsystems are very similar to Anik A, but the solar array diameter is 13% larger, thus increasing its output power. Marisat is heavier than Anik A and used the larger payload capacity of the Delta 2914 launch vehicle.

Marisat has a new communication subsystem. Three UHF channels are provided for Navy use, two with 25-kHz bandwidth and one with 500-kHz bandwidth. Each channel has a redundant transistor amplifier. For commercial use, there are two 4-MHz bandwidth channels, one for ship-to-shore communications and one for shore-to-ship. These channels use L-band frequencies between the satellite and ships and C-band between the satellite and shore stations. TWTs are used for both L-band and C-band transmissions, and the L-band TWT can be commanded to any of three power levels. The low-power level was used when all Navy channels were operating; as Navy requirements decreased, the higher-power levels were switched on.

Marisat has nine communication antennas. Three helices backed by truncated cones form a UHF array with a 30-deg beamwidth. A narrower beamwidth is not practical because of the larger antenna that would be required. Four smaller cone-helix antennas form an L-band array with a 20-deg beamwidth. Two earth coverage horns are used at C-band, one for transmitting and one for receiving. Other Marisat details are as follows:

Satellite

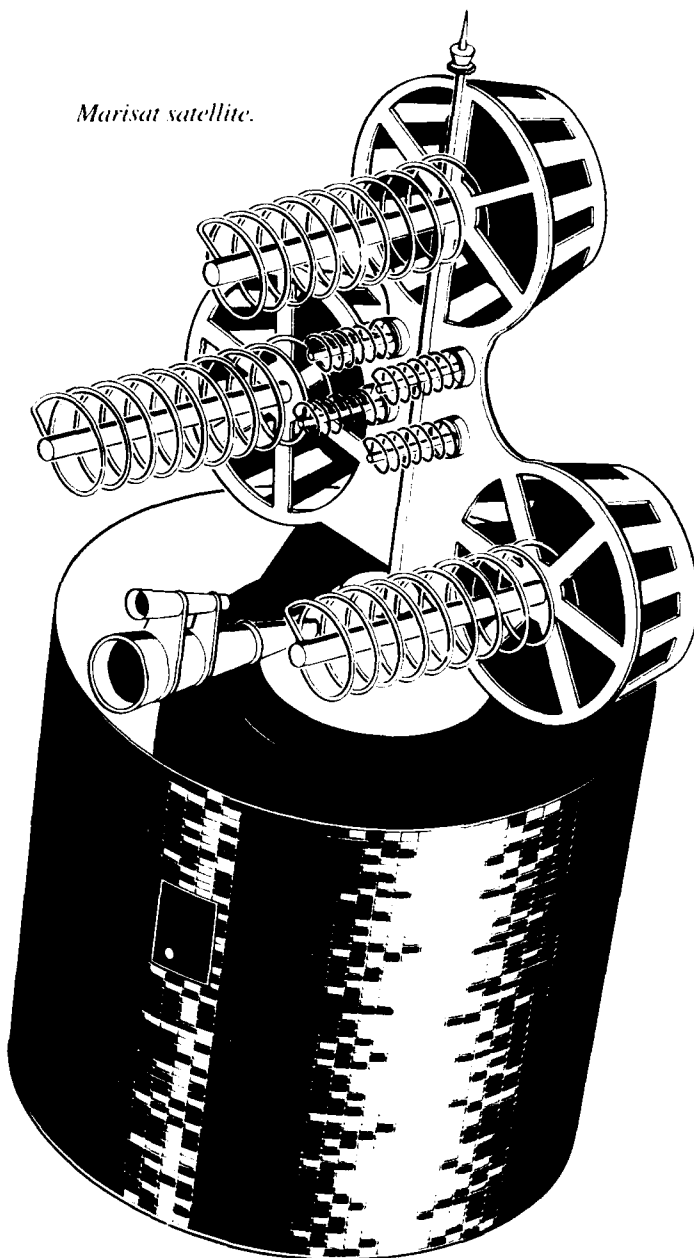
Cylinder, 85-in. dia., 63-in. height (150 in. overall)

720 lb in orbit, beginning of life

Solar cells and NiCd batteries, 335 W at beginning of life, 305 W at end of life

Spin-stabilized, 100 \pm 15 rpm, antenna pointing error, $<\pm 0.65$ deg each axis

Marisat satellite.



Configuration

UHF: one 500-kHz channel and two 25-kHz channels
L- and C-band: two 4-MHz channels (one L to C, one C to L)

Capacity

500-kHz channel: approximately five 2400-bps links and seven-teen 75-bps links

25-kHz channel: 2400-bps link

4-MHz channel (L to C): nine voice circuits or 110 teletype cir-cuits

4-MHz channel (C to L): one, five, or nine voice circuits and 44, 66, or 110 teletype circuits (depending on ERP)

Transmitter

UHF: 248- to 260-MHz band

Redundant solid-state amplifiers

65 W, 28 dBW (500-kHz channel) edge of earth

20 W, 23 dBW (per 25-kHz channel) edge of earth

L-band: 1537 to 1541 MHz

Redundant three-level TWTs

7, 30, or 60 W; 20-, 26-, or 29.5-dBW ERP edge of earth

C-band: 4195 to 4199 MHz

Redundant 5-W TWTs, 18.8-dBW ERP (specification) edge of earth (if at saturation; however, this transmitter will al-ways be operated linear), in-orbit ERP 1 to 1.5 dB above specification

Receiver

300- to 312-MHz band, 1638.5 to 1642.5 MHz, 6420 to 6424 MHz

Redundant receivers on each frequency

Noise figure: 4.2, 4.9, 8.8 dB

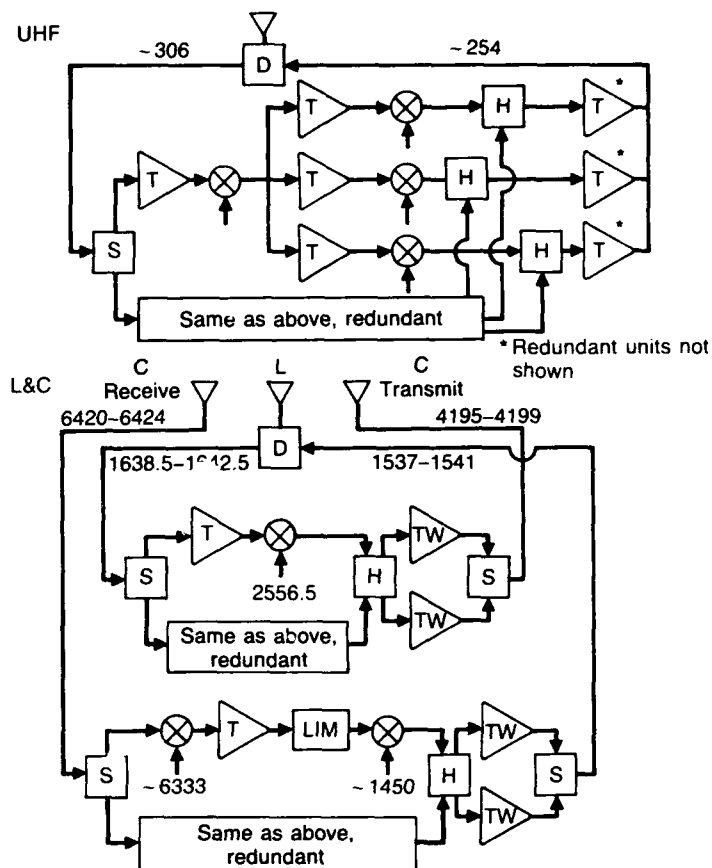
G/T (edge of earth): -18, -17, -25.4 dB/K

Antenna

UHF: three cone-helix antennas, each 48 in. long, 30-deg beam-width, 12.1-dB gain (transmit), 12.6-dB gain (receive) at ± 9.5 deg

L-band: four cone-helix antennas, each 15 in. long, approxi-mately 20-deg beamwidth, 14.4-dB gain at ± 9.5 deg

C-band: two horns (one transmit, one receive), approximately 18-deg beamwidth, 16-dB gain at ± 9.5 deg



Marisat communication subsystem.

All circular polarization

Design life

Five years

Orbit

Synchronous equatorial (≤ 3.5 -deg inclination), stationkeeping to $\pm 0.5^\circ$ E-W, inclinations 8 to 9 deg by 1991

Orbital history

1: launched 19 February 1976, 106° W longitude, in use until 1983, Inmarsat spare since 1983

2: launched 9 June 1976, 72° E longitude, in use until 1985, In-marsat spare since 1985

Marisat coverage areas (1976 to 1982).

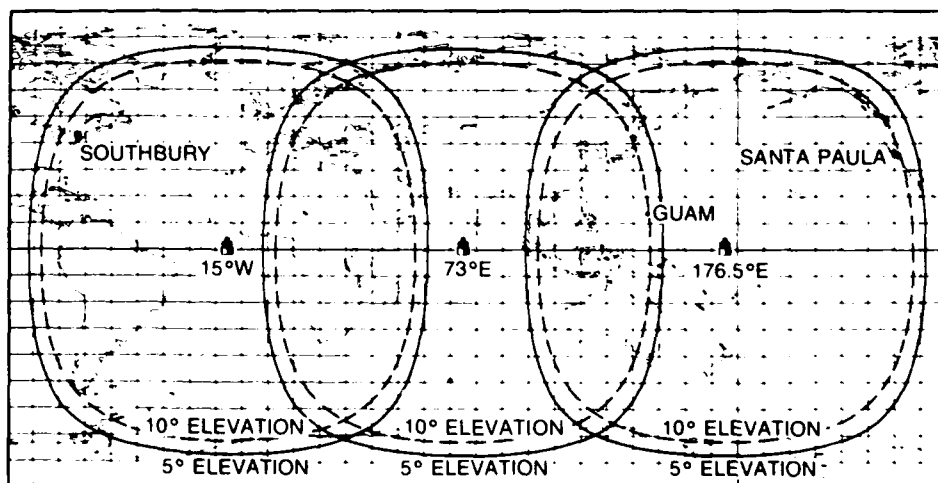


Table 1. Marisat Terminal Characteristics

PARAMETER	SHORE STATIONS	SHIP STATIONS
Frequency band	C ^a	L
Antenna diameter, ft	42	4
Transmit gain, dB	56.0	23.5 ^b
Transmitter power, W	3000	40
ERP, dBW	72-85	36-38
Receive gain, dB	53.2	23.5 ^b
G/T, dB/K	31.4	> -4
Beamwidth (transmit/receive), deg	0.26/0.4	10-11
Polarization	Circular	Circular

^a The shore stations can operate at L-band for testing.

^b Nominal. ERP and G/T are the controlling specifications.

3: launched 14 October 1976, 176°E longitude, in use until 1983, Inmarsat spare since 1983

2 and 3 were in opposite positions through 1983, 1 was moved from 15°W about 1989

Delta 2914 launch vehicle

Management

Developed by Hughes Aircraft Company for Comsat General Corporation (UHF capacity leased to the United States Navy, C/ L-band capacity leased to Inmarsat since 1982)

Operated by Comsat General Corporation

All three Marisat satellites are in orbit. The first was launched in February 1976 and placed over the Atlantic Ocean. It began Navy service in March 1976, but the start of commercial service was delayed until July 1976 because of problems with the C-band equipment. The second Marisat was launched in June 1976 and was providing both naval and commercial service over the Pacific Ocean by August. The third satellite was launched in October 1976 to provide service to the Navy in the Indian Ocean region. Commercial service with this satellite began in November 1978 with a terminal in Japan. Signal-quality reports for both types of service were good as soon as the system began operating; the expected improvements relative to terrestrial transmission links were fully realized. The coverage areas of the three satellites, as they were during their early lives, are shown.

Commercial service started on a limited basis, because of the small number of terminals and because most of the satellite power was required for the Navy channels. Gradually, the Navy use decreased and commercial use increased. Commercial services include telex, voice, facsimile, and data (up to 4800 bps) in both directions. These services are used by tankers, cargo, passenger and fishing vessels, offshore oil platforms, and private yachts. In 1981, 56 kbps ship-to-shore service was initiated, primarily for data transmissions from seismic survey vessels. On 1 February 1982, control of the three Marisats was transferred to Inmarsat. By the summer of 1983, Inmarsat had newer, more capable satellites in the Atlantic and Indian Oceans, and those two Marisats became spares for Inmarsat. The Pacific Marisat continued in active service until 1985. Inmarsat continues to lease all three Marisats to serve as spares. The most recent lease goes through 1992.

As part of this lease, one satellite was moved to a longitude centered on North America to provide services for land mobile terminals.

The primary Marisat ground terminals are located in Connecticut and California. They are both TT&C terminals and shore terminals for commercial communications for the Atlantic and Pacific satellites, respectively. A TT&C terminal at Fucino, Italy serves the Indian Ocean satellite. For the TT&C function, the terminals are connected to a system control center in Washington, D. C., where telemetry and tracking data are processed. Commands are normally initiated at the control center but can be initiated at the terminal.

The communication terminals are the link between the Marisat system and the regular terrestrial communication networks. The terminals can handle duplex voice and telegraph signals, 2400-bps data, and simplex ship-to-shore data and telegraphy. A computer at each terminal keeps traffic records, assigns satellite channels (i.e., transmission and reception frequencies) to users, and controls transmission path switching. Channel assignments are made in response to calls initiated from ships or through the terrestrial networks. In addition, the shore station can transmit broadcast messages to all ships of a specific company or nationality, or to all ships in a certain geographic area. Signaling related to channel assignments is handled through dedicated request (ship-to-shore) and assignment (shore-to-ship) channels. Emergency requests are handled with a priority above all other messages.

Table 1 gives the basic characteristics of the shore and ship terminals which were in use with the initial Marisat system. The ship terminal is capable of receiving and transmitting one voice channel or 2400 bps data. Approximately 160 of the larger ship terminals were in use by December 1978, increasing to 600 in early 1981 and 1000 by January 1982. These terminals have operated within the Inmarsat system since it came into being. The Inmarsat System section describes the evolution of terminal sizes and numbers since then.

The Navy provided its own ship and shore terminals for use with the UHF channels. These terminals were also being used with the FLTSATCOM satellites but could be tuned to Marisat frequencies. The shore terminals had both communications and network control functions.

* * * * *

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TDRSS

Throughout most of its history, NASA depended on a worldwide network of ground stations for TT&C support of their satellites. These stations must be connected with CONUS mission control centers by an extensive communications network. However, the contact these stations have with the satellites they support is limited by geometry. Continuous contact is possible for satellites at synchronous altitude, but many satellites are in relatively low-altitude orbits (<1000 nmi). For these satellites, contact durations range from a few to perhaps 20 min, with periods of several hours between contacts. The result is that a mission control center can communicate with a satellite for a small fraction of time (typically $\leq 15\%$). These limitations are being overcome by a

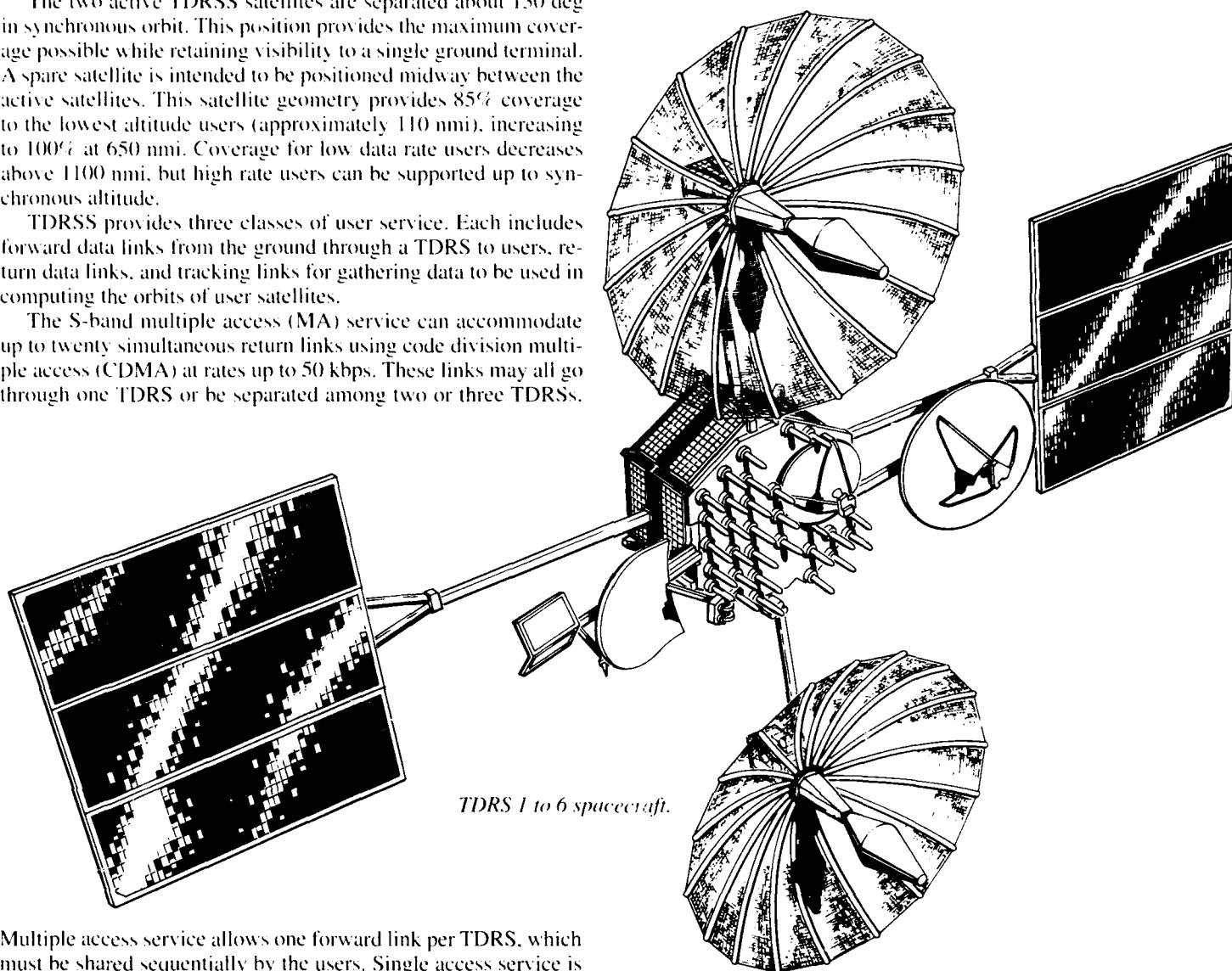
Tracking and Data Relay Satellite (TDRS) System (TDRSS) [1-38]. In addition to improving coverage, the TDRSS is allowing NASA to close most of its overseas facilities.

Initial studies of the TDRSS were conducted in the early 1970s. Extensive system definition work was done in 1973, and two contractors completed system designs in early 1976. At the same time, NASA, Congress, and the General Accounting Office were analyzing the relative merits of leasing or purchasing the system. The decision was that NASA should lease the system, and at the end of 1976, NASA awarded a contract for the development and ten years of operation of TDRSS. The contract included both space and ground segments of the system.

The two active TDRSS satellites are separated about 130 deg in synchronous orbit. This position provides the maximum coverage possible while retaining visibility to a single ground terminal. A spare satellite is intended to be positioned midway between the active satellites. This satellite geometry provides 85% coverage to the lowest altitude users (approximately 110 nmi), increasing to 100% at 650 nmi. Coverage for low data rate users decreases above 1100 nmi, but high rate users can be supported up to synchronous altitude.

TDRSS provides three classes of user service. Each includes forward data links from the ground through a TDRS to users, return data links, and tracking links for gathering data to be used in computing the orbits of user satellites.

The S-band multiple access (MA) service can accommodate up to twenty simultaneous return links using code division multiple access (CDMA) at rates up to 50 kbps. These links may all go through one TDRS or be separated among two or three TDRSSs.



TDRS 1 to 6 spacecraft.

Multiple access service allows one forward link per TDRS, which must be shared sequentially by the users. Single access service is available at S-band (SSA) or K-band (KSA) for two users per TDRS. Single access service includes simultaneous forward and return links. Return link data rate limits are 12 Mbps for S-band and 300 Mbps for K-band. Users require as little as 2- to 5-W transmitters and a low-gain antenna to transmit about 1 kbps on the MA return and up to about 20 W and a 6-ft-diameter steerable antenna to transmit 100 Mbps on the KSA return link.

The central body of the TDRSS is hexagonal, about 8 ft across and 5 ft in height. This body and the solar arrays are derived from the FLTSATCOM design.

The large antennas with the mesh surface are 16 ft in diameter and are deployed in orbit, being folded like an umbrella during launch. They are used for the single access user links at both S- and K-band. They can be pointed up to 90 deg off nadir away from the satellite or up to 30 deg off nadir toward the satellite body and rotated ± 90 deg from nadir about the axis that includes their deployment booms. The circular antenna to one side of the satellite body is for the link with the ground terminal. The thirty helix antennas on the face of the satellite form the phased array for the S-band multiple access links with the users.

The D-shaped antenna to one side of the body and the circular antenna on the face of the satellite are not used by TDRSS. They are part of the Advanced Westar subsystem, which shares the spacecraft with the TDRSS equipment. The Advanced Westar

equipment was not removed when that mission was terminated. The portions that are shared and those that are dedicated to the two missions are indicated in the figure. Spacecraft design and the TDRSS mission communication characteristics are as follows:

Satellite

Hexagonal prism body, approximately 8 ft across, 5 ft in height, 57 ft between tips of deployed solar arrays, 43 ft across large deployed antennas

Approximately 5000 lb in orbit, beginning of life

Sun-tracking solar array and NiCd batteries, 1700 W end of life

Three-axis-stabilized using reaction wheels, ± 0.1 deg in pitch and roll, ± 0.25 deg in yaw

Liquid monopropellant propulsion for on-orbit use

Configuration

Multiple S-band and K-band transmitters and receivers, all connected to an IF processor

Capacity

S-band multiple access (MA): one forward link at 0.1 to 10 kbps, up to twenty simultaneous return links at 0.1 to 50 kbps each

S-band single access (SSA): two forward links at 0.1 to 300 kbps each, two return links at 0.1 kbps to 12 Mbps each

K-band single access (KSA): two forward links at 1 kbps to 25 Mbps each, two return links at 1 kbps to 300 Mbps each

Each single access antenna can support one forward and one return link at S- or K-band at a time (one forward and one return link at both frequencies simultaneously is possible to a single user or to separate users less than 0.4 deg apart)

Transmitter

(ERP values are requirements, which were generally exceeded by on-ground measurements)

MA: 2103.4 to 2109.4 MHz

35 W total power, 3.5 W each from twelve phased elements (eight required at end of life)

34-dBW ERP

SSA: in the band 2025.8 to 2117.9 MHz

15/26-W TWT (Satellites 1 to 6), solid-state amplifier (Satellite 7)

44.0/46.4-dBW ERP

KSA: in the band 13.75 to 13.8 GHz

1.5-W TWT (Satellites 1 to 6), solid-state amplifier (Satellite 7)

49.4-dBW ERP

K-band to ground terminal: 13.4 to 14.05 GHz

One TWT for each of two links, 30 W nominal at beginning of life, 22 W minimum at end of life, operated with a few dB backoff

50.9/52.8-dBW ERP

Receiver

(G/T values are requirements, which were generally exceeded by on-ground measurements)

MA: 2285 to 2290 MHz

Transistor preamplifier for each of thirty antenna elements

-14.1 dB/K G/T per element at edge of coverage

Approximately -1 dB/K overall G/T (-2 dB/K end of life)

SSA: in the 2200- to 2300-MHz band

Parametric amplifier first stage (Satellites 1 to 6), FET preamplifier (Satellite 7)

8.9 dB/K G/T

KSA: in the 14.891- to 15.116-GHz band

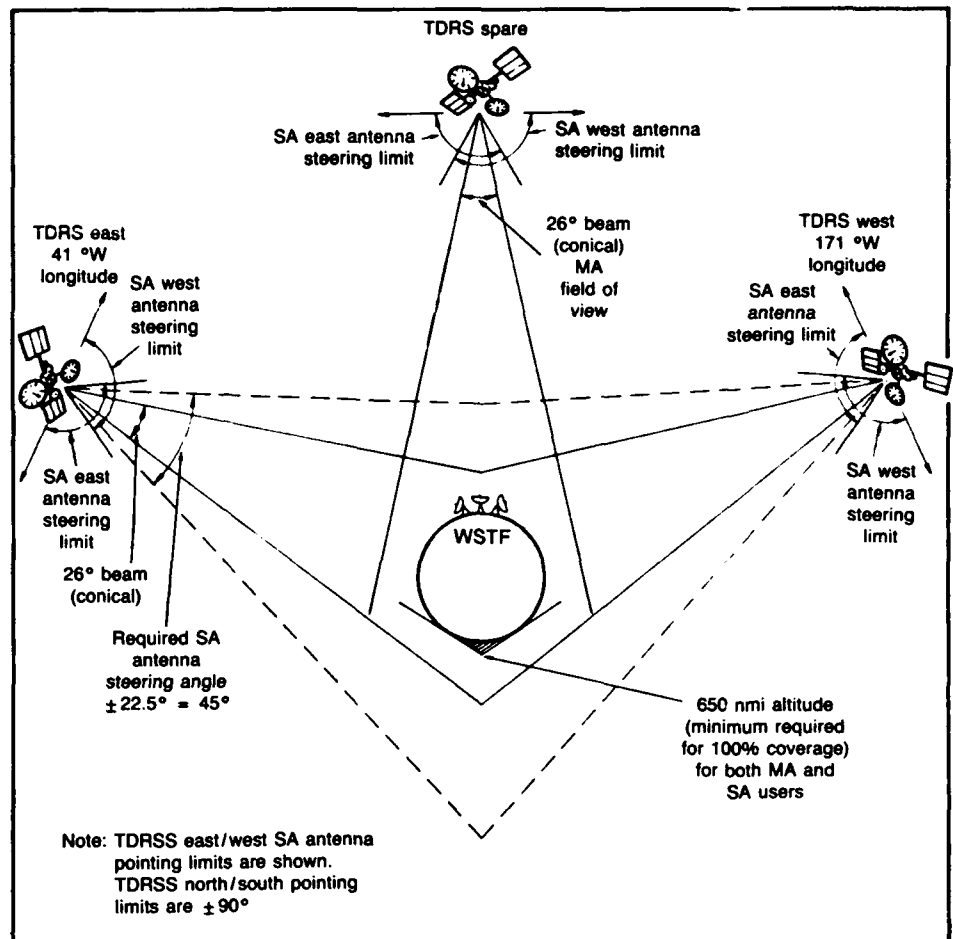
Parametric amplifier first stage (Satellites 1 to 6), FET preamplifier (Satellite 7)

24.4 dB/K G/T

K-band from ground terminal: 14.6 to 15.25 GHz (for FDM composite of multiple links)

Transistor preamplifier

10.0 dB/K G/T



TDRS system.

Antenna

MA: thirty-element phased array (only twelve elements used for transmission), 15.4-dB peak element gain, 13-dB gain over 27-deg field of view, 13.8-dB combining gain, one transmit beam and up to twenty receive beams can be formed in the 26-deg field, circularly polarized

SSA and KSA: two 16-ft parabolas, 36.7/53.5-dB peak transmit gain, 37.7/54.6-dB peak receive gain, 0.5/0.6-dB pointing loss, 2-deg/0.28-deg beamwidth, circular polarization, open loop S-band pointing, autotrack

K-band pointing, steerable $\pm 90^\circ$ N-S and $30/90^\circ$ E-W (30 deg toward satellite body, 90 deg away)

K-band terminal link: 6.6-ft parabola, 45.3-dB peak transmit gain, 46.0-dB peak receive gain, 0.7-dB pointing loss, 0.7-deg beamwidth, linear polarization

Design life

Ten years

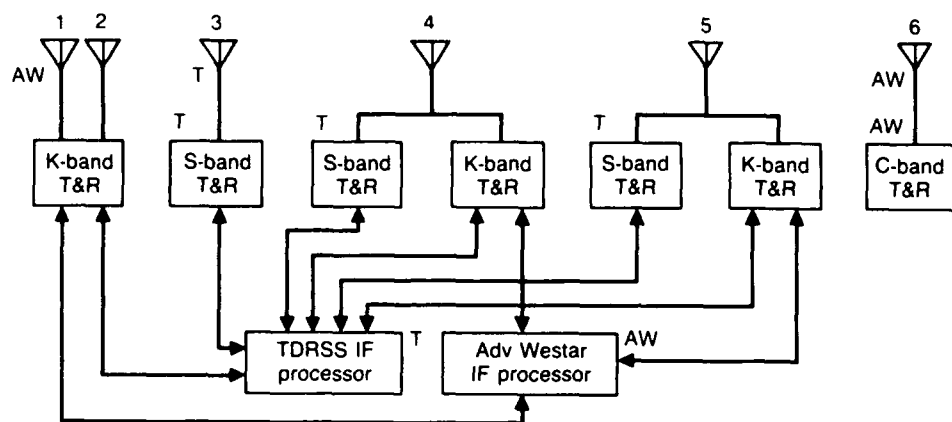
Orbit

Synchronous, ≤ 7 deg inclination, E-W stationkeeping to ± 0.1 deg

Orbital history

1: launched 4 April 1983, active satellite at 42° W longitude until 1989, spare at 170° W longitude

2: destroyed by Shuttle explosion January 1986



Antennas:

- 1 Body-mounted parabola
- 2 and 6 Deployed solid reflectors
- 30-element phased array
- 4 and 5 Deployed mesh reflectors

- T Equipment used only by TDRSS
- AW Equipment used only by advanced Westar;*
- other equipment is used by either
- T&R Transmitters and receivers

TDRS communication subsystem.

* Prior to AW cancellation (see text).

3: launched 29 September 1988, active satellite at 174° W longitude

4: launched 13 March 1989, active satellite at 41° W longitude

5: launched 2 August 1991

6: launch scheduled late 1992

7: available 1992, launch scheduled 1995

Shuttle/IUS launch vehicle

Management

Developed by TRW Defense and Space Systems Group for Space Communications, Inc. (for lease to NASA)

Operated by Contel Federal Systems (formerly Space Communications, Inc.)

Seven uplinks from the ground terminal to the TDRS each transmit one of the forward data and tracking signals or command and control data for the spacecraft. The forward portion of the IF processor frequency demultiplexes these uplinks, and the return portion of the processor combines all the return links and the spacecraft telemetry for the composite downlink to the terminal. The downlink uses two polarizations, one for an FDM combination of one KSA link, the two SSA links, the signals from the 30-MA antenna elements, and the TDRSS telemetry. The other polarization is for the second KSA return link. For reducing satellite complexity, the phased array beam-forming computations and receiver phase shifters, the single-access antenna autotracking computations, and the master oscillator for the satellite frequency generator are all in the terminal. The uplinks and downlinks include all signals necessary for these functions.

The TDRSS ground terminal is located at White Sands, New Mexico, and the building includes all equipment necessary for TDRSS operations as well as space for NASA to install mission-peculiar equipment. Three 60-ft antennas handle the uplinks and downlinks for three active satellites and one spare. The terminal also has antennas for S- and K-band user simulations, an S-band TT&C antenna (used during launch and positioning, and if the K-band TT&C fails), and a K-band TT&C antenna. NASA provides for communications between the TDRSS terminal and mission control centers, primarily via domestic communication satellites.

The initial ground terminal is called the White Sands Ground Terminal (WSGT). In 1989, NASA awarded a contract for development of a Second TDRSS Ground Terminal (STGT). The STGT will provide the same function as WSGT, but with increased reliability and automation. The STGT will add another three 60-ft antennas to the TDRSS ground segment, thereby allowing NASA to use four active satellites in the mid-1990s and beyond. The STGT will be in operation starting in 1993. Afterwards, WSGT will be taken out of service and much of its equipment replaced with copies of STGT equipment. It will reenter service in 1994.

The original NASA contract for TDRSS was with Western Union Space Communications. In 1980, the contract was transferred to a partnership of Western Union, Fairchild, and Continental Telephone, called Spacecom. At the end of

1982, the contract was modified to eliminate the Advanced Westar mission. At first, sharing the spacecraft between two missions seemed to be an economic advantage to both NASA and Western Union. As the program progressed, however, both parties realized they would do better with separate satellites. (Western Union had already launched the Westar IV and V because of the delay in orbiting the Advanced Westar mission.) Therefore, NASA paid Spacecom to gain full control of the satellites. This payment compensated Spacecom for the revenues it would have received from the use of Advanced Westar. In January 1983, Western Union sold its share of Spacecom to the other two partners; and in 1985, Fairchild sold its share, leaving Continental Telecom (formerly Continental Telephone) as sole owner of Spacecom. In 1990, a new contract transferred ownership of the system to NASA but retained Contel as the operator.

The C-band equipment on the first six TDRS spacecraft is separate from all the TDRSS mission equipment, and the two can be operated simultaneously. After Satellite 1, the C-band antenna patterns were modified to allow transoceanic communications from the normal TDRS operating locations. In 1990, the C-band equipment on Satellites 3 and 4 was leased to Columbia Communications. Their use of it is described in an earlier section on international satellites.

The TDRSS spacecraft are launched on the Shuttle and boosted to synchronous orbit by the Inertial Upper Stage (IUS). The first launch was scheduled for 1980, but the Shuttle was unable to meet that schedule. The first launch actually occurred in April 1983. The IUS malfunctioned and left the TDRSS in an elliptical orbit. In May and June, through a long sequence of thruster firings, the spacecraft was moved to synchronous orbit. By early August, MA service to the low-altitude Landsat 4 had been demonstrated. High rate service was initiated a few months later. The next TDRS launch was delayed until the IUS problem was corrected. Meanwhile, component failures on TDRS 1 reduced its usefulness. The TDRS 2 launch was delayed again to make changes to fix the problems that caused the failures. In 1986, this satellite was destroyed in the Shuttle explosion.

When Shuttle launches resumed, the first carried TDRS 3. It was positioned over the Pacific to give NASA one satellite over each ocean. TDRS 4 was launched in 1989 and replaced TDRS 1

over the Atlantic. Because of minor failures on TDRS 3, TDRS 1 was moved to the Pacific as a spare. TDRS 5 was launched in August 1991; after checkout, it will replace TDRS 3 which will move to 62°W longitude and become the system's spare satellite.

The next launch is scheduled for late 1992. A seventh satellite is being built under a new contract. It will be ready in 1992 but is not expected to be launched until 1995. This contract has an option for an eighth satellite. Some parts have been ordered, but construction of the satellite has not been authorized yet. These two satellites have newer electronics than the first six and do not have the C-band equipment.

NASA has been studying an Advanced TDRSS (ATDRSS) since 1986. This system will continue all the services supplied by TDRSS, with certain improvements in MA service. It will also add an additional Ka-band single access service in the 23- to 28-GHz spectrum with return data rates up to about 650 Mbps. Three contractors finished system definition studies of ATDRSS in mid-1991. One will be selected in fall 1992 to begin development of the satellites. The first ATDRSS launch will not occur before 1997.

* * * * *

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MSAT

In 1980, the Canadian government undertook a study of a communication satellite system to provide service to mobile terminals, including land vehicles, ships, and airplanes. In 1982, the idea evolved into a joint Canada-NASA effort. At the same time, NASA asked the FCC to set aside a portion of the 806- to 890-MHz band for this type of system. In 1983, two United States companies submitted applications to the FCC for permission to develop and operate mobile communication systems using satellites. As a result of this commercial interest, Canada and NASA agreed, in 1984, to support separate, but coordinated, commercial systems in each nation. The Canadian name for this system is MSat; in the United States, the generic term MSS (mobile satellite service) is commonly used [1-13].

The goal of an MSS system is to provide voice, message, and data communications, and perhaps position determination also, to mobile users. In urban areas, these services can be provided by terrestrial systems, but they cover less than 15% of the North American land mass and even less of ocean areas near the continent. Satellite systems can cover all areas of interest and afford distance-insensitive prices and flexible call routing regardless of the mobile user's location. However, satellite signals are severely attenuated by large buildings in urban centers, so satellite and terrestrial systems do have complementary roles.

As a result of the early applications, the FCC started an inquiry into the appropriate national policy for these systems. In the spring of 1985, twelve companies (including the original two) submitted proposals in response to an FCC invitation. There was considerable variation among the twelve. All were intended to serve mobile users and fixed users who are remote from terrestrial communications. Services included one or more of voice; low rate, short textual or numeric messages; and position determination. Frequencies were either the 800-MHz band or L-band (approximately 1.5 GHz) or both between satellites and mobile terminals. Other variations included the number of antenna beams, the number of channels, and power levels.

The twelve applications emphasized several policy questions that took the FCC over a year and a half to resolve. The primary questions were: which frequencies to use, how many competing systems to allow, and whether to distinguish between various types of services and between services to air, land, and maritime users. The FCC decision was announced at the end of 1986. The key points were that the United States should have an MSS system, that this system serve all types of mobile users, that L-band be used for links between mobile users and satellites and Ku-band

between fixed ground sites and satellites, that the satellites be provided by a single consortium, and that services be offered by any qualified entity using satellite capacity provided by the consortium. This decision was generally accepted by the interested parties, and the main effort through 1987 was to form the consortium. Some of the original applicants dropped out, but by the end of 1987 eight companies had reached an agreement, and the consortium was formally incorporated in the spring of 1988 as American Mobile Satellite Corporation (AMSC).

At about the same time, Telesat Canada, which was the designated satellite owner for the Canadian part of the system, formed Telesat Mobile Inc. (TMI) to manage its MSat work. AMSC and TMI continued the intergovernmental cooperation on the system and reached agreement on a fully coordinated approach. Their system [14-23] consists of two satellites, identical in design, with multiple spot beams covering all of North America. One satellite belongs to each company, but they are being procured together. Each company will normally use its own satellite for service to its own country. Each satellite serves as a backup to the other, eliminating the cost of an in-orbit spare satellite, and excess capacity on either satellite can be leased to the other operator. Each company has its own control center; but they use a common design, so that each can support the other.

In 1988, AMSC filed a formal application with the FCC and was granted approval in 1989. In 1990, AMSC and TMI put out a request for proposals for their two satellites and chose a contracting team near the end of the year. The team has a United States contractor building the spacecraft and a Canadian contractor building the communications payload and integrating the spacecraft and payload.

The appearance of MSat is dominated by the two large antenna reflectors. These reflectors, about 17 ft in diameter, plus multiple feed elements on the satellite body, form the multiple L-band beams. One antenna is for transmission and one for reception. A 2-ft antenna on the satellite body forms a single Ku-band pattern shaped to match the North American land mass. The deployed solar arrays and the support subsystems within the spacecraft body are similar to those used on Aussat B and the Galaxy IV and VII satellites. Tentative details are:

Satellite

Rectangular body approximately $6 \times 7 \times 7$ ft, span across solar arrays 69 ft, span across large reflectors 67 ft

Approximately 3400 lb in orbit, beginning of life

Sun-tracking solar arrays/NiH₂ battery, approximately 3000 W

Three-axis stabilization using gimballed momentum wheels

Configuration

Multiple Ku-band to L-band channels (fixed sites to mobiles)

Multiple L-band to Ku-band channels (mobiles to fixed sites)

Ku-band to Ku-band channel (fixed site to fixed site)

Transmitter

L-band: 1530 to 1559 MHz

Sixteen solid-state power amplifiers, each approximately 40-W output

ERP (total for all channels) 55.5 dBW over 95% of the land area, 54 dBW over 100% of the service area (land plus ocean)

Ku-band: 10.75 to 10.95 GHz (11.7 to 11.9 GHz on future satellites)

Approximately 5-W output

ERP 36 dBW over 95% of land area

Receiver

L-band: 1626.5 to 1660.5 MHz

G/T 2.8 dB/K over 95% of land area, 1.8 dB/K over 100% of service area

K-band: 13.0 to 13.15 and 13.2 to 13.25 GHz (14.0 to 14.2 GHz on future satellites)

G/T -3 dB/K over 95% of land area

Antenna

L-band: two reflectors, 17- to 20-ft dia., with multiple feed elements (cup-dipoles) to form multiple beams covering all of Canada, the United States, coastal waters to 200 nmi offshore, and perhaps Mexico

Ku-band: one reflector, approximately 2-ft dia. with multiple feed horns to generate one beam covering North America

Design life

Ten years or longer

Orbit

Synchronous equatorial, 101°W longitude (AMSC), 106.5°W longitude (TMI), 62°W and 139°W longitude (future AMSC satellites)

Orbital history

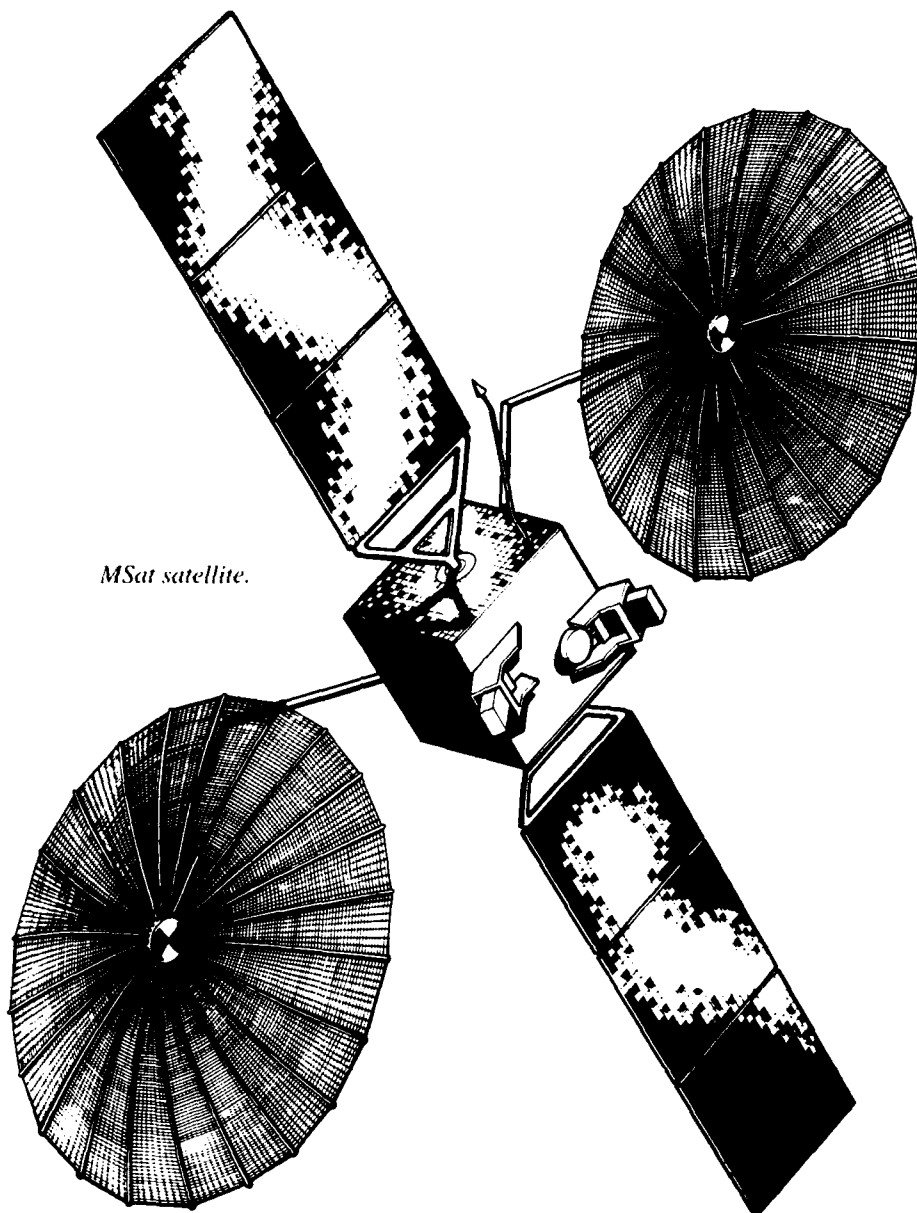
TMI launch planned in 1994, Ariane launch vehicle

AMSC launch planned in 1995

Management

Developed for AMSC and TMI by Hughes Aircraft Company and Spar Aerospace

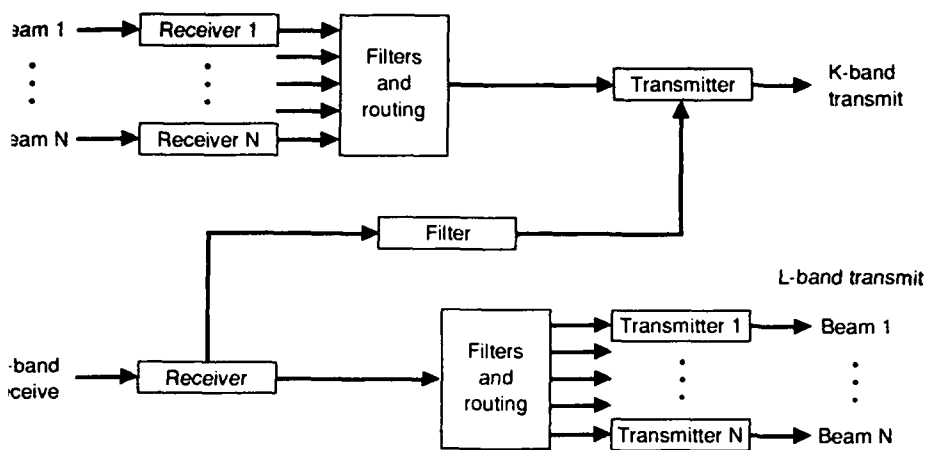
Operated by AMSC, and by Telesat Canada for TMI



The satellite communication subsystem has two main paths, L-band to Ku-band and Ku-band to L-band. The first is for communications from mobiles to fixed stations, and the second is for fixed stations to mobiles. A secondary path, Ku-band to Ku-band, is for coordination and network control, connecting the mission control center and the fixed sites. Two mobiles can communicate only by a double hop through a fixed site.

The L-band spectrum is divided into many pieces corresponding to various specific uses and types of mobile terminals. Each piece of the spectrum will correspond to a filter in the L-band transmitter or receiver. These filter banks, transmitters, and receivers will be replicated for each L-band antenna beam. Within the filtered bands, each individual signal will have a 5-kHz bandwidth. These 5-kHz channels will be assigned on demand with consideration of priorities and returned to a commonly available pool when no longer needed. The priority aspect of the demand assignment scheme will ensure that channels are always available for emergency communications. Since the instantaneous traffic

band receive



MSat communication subsystem.

and in each beam will vary considerably over a day, the transmitter power in each beam will also be varied.

The MSat system will support transmission of voice, data, messages, paging, and position location information. Any of these types of communication may be part of a private network or interconnected with the public switched network. To initiate a transmission, a request is sent over a signaling channel to the network control center. The center assigns L-band and Ku-band frequencies and, for public switched network use, it also assigns the fixed site closest to the requested destination. Upon receiving these assignments, the mobile and the fixed site begin communication.

AMSC and TMI have begun limited service using satellite capacity leased from Inmarsat. All traffic will be transferred to their own satellites when they are launched, probably in 1994 or 1995.

* * * * *

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UNITED STATES DIRECT BROADCAST SATELLITES

In 1963, the International Telecommunications Union (ITU) established the Fixed-Satellite Service (FSS) and Broadcasting-Satellite Service (BSS) as distinct radio services. In 1971, the ITU allocated specific frequency bands to both FSS and BSS. The FSS was intended for all types of communications, via satellite, between relatively large, fixed ground terminals. The BSS was intended for transmission of television from a central terminal to moderately sized community reception terminals or small individual reception terminals. The latter corresponds to the term *direct broadcast*, which means direct from satellite to home, in contrast to cable distribution or terrestrial rebroadcast of television signals received from a satellite.

ATS 6, CTS, and the Japanese broadcasting satellite, launched in 1974, 1976, and 1978, respectively, were the first satellites to demonstrate high-power broadcasts to simple community and home receivers with antenna diameters as small as 2 ft. In 1977, an ITU conference defined direct broadcast system characteristics and assigned satellite locations and frequencies for all countries except those in North and South America. An ITU conference in June and July 1983 did the same for the Americas. The FCC began preparations for the 1983 conference in the summer of 1980. In October of that same year, the FCC undertook to define, allowing for comments from all interested parties, a direct broadcast system policy. In April 1981, this investigation concluded that such systems are in the public interest and should be permitted to develop with a minimum of regulation.

At the same time, however, direct broadcast systems of a different nature were developing in the marketplace. The first type is now called a low-power direct broadcasting satellite or system (DBS). Low-power DBS is home reception of 4-GHz FSS downlinks from many of the Canadian and United States satellites previously discussed. These downlinks are intended for distribution of network television to affiliate local broadcasting stations and for distribution of various types of television programming to cable television systems. When this started, in the late 1970s, a typical receiving antenna diameter was 33 ft. However, with improvements in low-noise amplifiers, and the realization that a home viewer will have good picture quality with less signal strength than a commercial distributor requires, home reception became possible with a receiver that costs as little as \$1000, with antenna diameters as small as 6 ft. At the present time, about three million homes are equipped to receive the 4-GHz FSS downlinks, making low-power DBS a significant industry. Furthermore, this entire industry is based on intercepting signals intended for another class of receivers. Such home reception, when limited to private use in the home, was given legal recognition by Congress in 1984.

Medium-power DBS refers to home reception of 12-GHz FSS downlinks. The name occurs because these downlinks usually have higher power than 4-GHz downlinks. As a result, antenna diameters may be as small as 4 ft and receiver prices as low as \$500. There are two types of medium-power signals: those intended for commercial reception and intercepted by home receivers, and those intended for home reception. Medium-power DBS is a more recent development, and the number of homes with receivers is probably about 50,000. Like low-power DBS, most of these are in the United States. Some are in Canada, aimed at either Canadian or United States satellites, and fewer are in other places close enough to the United States to have adequate signal levels.

High-power DBS refers to signals transmitted by high-power BSS satellites and intended for home reception. High-power systems are designed such that receivers will cost \$300 to \$600 and use 2- to 3-ft antennas. The satellite and systems discussed here are all for high-power DBS; none is in operation yet [1-23]. A good review and comparison of low-, medium-, and high-power DBS is in [22].

The first application for a high-power DBS system was filed by Satellite Television Corporation (STC), a subsidiary of Comsat Corporation, in December 1980. The FCC combined that application with thirteen others that were received by the July 1981 deadline for first-round consideration. STC's application was approved in October 1982 and seven others the next month. Approval meant that a satellite construction permit would be granted on two conditions:

- The satellite design would have to be modified to comply with the results of the 1983 ITU conference.
- Under *due diligence*, satellite construction would have to begin or a contract for satellite construction would have to be completed within one year after the permit was issued (eventually, first-round applicants were given about two years).

The second condition also has been applied to all construction permits granted in succeeding rounds. If an applicant satisfies the due diligence condition, possibly after an extension of the one-year period, an orbital location and specific DBS channel frequencies are assigned by the FCC. The locations and frequencies are drawn from those allocated to the United States by the ITU, on a first-come, first-served basis. Applicants who fail to show due diligence have their permits cancelled.

In January 1984, the eight approved applicants all submitted modifications to satisfy the ITU conference decisions. In the same month, seven second-round applications were received. In the summer of 1984, two first-round applicants withdrew. Their permits, and two others, were revoked by the FCC in October 1984 for lack of due diligence. In 1984, STC announced that it would no longer be a DBS operator but did not cancel the order for construction of its satellites. One was sold to Japan as BS-2X; later, the other also was sold to Japan as BS-3H.

Six second-round permits were granted in December 1984 and January 1985. By this time, the FCC was receiving requests to modify previously submitted applications. Modifications that required no additional orbit locations and spectrum were approved. Typically, these modifications were to double the coverage of a satellite, because home receiver improvements or better modulation techniques permitted operation with a lower received power. Other modifications included requests for additional channels on a satellite. This modification would reduce the per-channel cost; but, because additional spectrum was required, the FCC placed these requests with new applications in whatever round was open at that time.

The third-round deadline was February 1985. Six permits were granted in September; three were new, and three were modifications of existing permits. The fourth round concluded near the end of 1986. Three permits were granted, all for modified versions of applications formerly approved in previous rounds. At the same time, the FCC authorized DBS systems to handle some nonvideo transmissions on a limited basis. The fifth-round deadline was in the spring of 1988. Nine applications were submitted; only three were from new applicants. In August 1989, the FCC granted permits to seven applicants; one other was deferred because of concerns about its anti-competitive nature, since the

Table 1. DBS Construction Permits

ROUND	PERMIT DATES	APPLICANT ^a	STATUS
1	Oct., Nov. 1982	Satellite Television Corp. CBS Direct Broadcasting Satellite Corp. Graphic Scanning Corp. RCA Americom U.S. Satellite Broadcasting Corp. Video Satellite Systems ^b Western Union Telegraph Co.	Reduced commitment since 1984, sold satellites in 1986 Withdrew, permit canceled in 1984 Gave up permit in 1985 to enter fourth round for more channels Permit canceled in 1984, entered third round Permit canceled in 1984, entered third round Satellites in construction Satellites in construction, purchased STC satellites in 1986 Withdrew, permit canceled in 1984
2	Dec. 1984, Jan. 1985	Advanced Communications Corp. Hughes Communications Galaxy, Inc. National Christian Network, Inc. National Exchange, Inc. Satellite Development Trust Syndicated Satellite Systems, inc	? (due diligence year expired) ^c Satellites in construction ? (due diligence year expired) ? (due diligence year expired) ? (due diligence year expired) Gave up permit in 1985 to enter fourth round for more channels
3	Sept. 1985	Advanced Communications Corp. Antares Satellite Corp. Dominion Video Satellite Corp. Graphic Scanning Corp. RCA Americom U.S. Satellite Broadcasting Corp.	Modified second-round (6 channels) permit to 8 channels, see comment above ? (due diligence year expired Sept. 1986) Modified first-round (12 channels) permit to 16 channels ? (due diligence year expired Sept. 1986) ? (due diligence year expired Sept. 1986) Modified first-round (6 channels) permit to 8 channels

Only applicants that were granted permits are given
Now called Dominion Video Satellite, Inc.
See text for explanation

wner also is a large operator of cable television systems. The
inth fifth-round applicant withdrew.

In 1990, there were nine active applicants: the seven approved
the fifth round, one remaining from the four previous rounds,
and the one deferred in the fifth round. Additional ventures were
nounced in 1990. However, although several applicants have

satellites on order, actual schedules are vague. Launch dates are
usually stated as desires or modified by "as early as." It is unlik-
ely that any high-power DBS satellites will be launched before
1994.

The fundamental reason for no launches after years of FCC
permits is financial. The early cost estimates were \$200 to \$800
million to put a system into operation; i.e., to get at least two sat-
ellites into orbit and in use. Recent cost estimates are rarely less

Table 2. DBS Characteristics

SYSTEM	NUMBER OF SATELLITES AND THEIR COVERAGE	CHANNELS PER SATELLITE	CHANNELS AVAILABLE TO ANY VIEWER ^a	APPROXIMATE ERP PER CHANNEL, dBW	RECEIVER ANTENNA DIAMETER, ft	SATELLITE CHANNEL NUMBERS ^b AND LOCATIONS
Dominion Video Satellite, Inc.	Two, each with two one-fourth CONUS beams	16 (eight per beam)	8	54	2	Channels 1-16 (8 per satellite) 119°W (both satellites)
Hughes Communications Galaxy, Inc.	Two, each one-half CONUS	16	16	51	2-4	Channels 1-32 (16 per satellite) 101°W (both satellites)
Satellite Television Corp.	Two, each full CONUS ^c	3	6	50-54 ^d	2.5	Channels 3, 5, 7, 110°W Channels 4, 6, 8, 110°W
U.S. Satellite Broadcasting Corp.	Two, each one-half CONUS	8	8	54	2	Channels 9-16 110°W Channels 9-16 148°W

Viewers located in coverage overlap areas can receive twice as many channels

Channels 1-16 are frequency interleaved with and on the opposite polarization of channels 17-32, in the 12.2- to 12.7 GHz band.

^c Initially, one-fourth CONUS, then one-half CONUS, now full CONUS.

^d ERP is weighted across CONUS by rainfall intensity and population density.

than \$400 million. The primary cost is for the satellites and for launching them, but developing quality programs to transmit through the satellites also is expensive. Furthermore, extensive competition from cable television, low- and medium-power DBS, and video tapes causes some financiers to be hesitant to support high-power DBS ventures.

One trend among the evolving high-power applications has been more channels per satellite and more area covered by each satellite. This definitely reduces the satellite cost for each channel, but not the cost of programs for the channels. For comparison, the first STC application had three channels per satellite with four satellites required to serve the entire United States. By 1989, the typical satellite had sixteen channels; only two were required to serve CONUS, although plans for service to Hawaii, Alaska, and Puerto Rico were uncertain. The increased number of channels is due both to the growing capacity of satellites to support the required transmitters and to improvements in receiver technology reducing the required satellite transmitter power.

As of 1990, the typical satellite had sixteen channels each with a transmitter power of 100 to 125 W. The channels are part of the thirty-two allocated by the ITU in the frequency bands 17.3 to 17.8 GHz for uplinks and 12.2 to 12.7 GHz for downlinks. The downlink ERPs are 50 to 54 dBW for an antenna beam that covers half of CONUS. For satellites designed to cover all of CONUS, either the ERP is reduced about 3 dB, or the number of channels is reduced to eight and the transmitter power doubled. Of the orbital locations assigned to the United States by the ITU, the FCC has decided that 61.5°W, 101°W, 110°W, and 119°W longitude will be for service to the eastern half of CONUS, and that 148°W, 157°W, 166°W, and 175°W longitude will be for service to the western half of CONUS. The four eastern locations can also be used for broadcasting to all of CONUS, if they do not cause interference to satellites operating from the western locations. Actual satellite designs are still evolving and have not been described in detail.

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EUROPEAN SATELLITES

European involvement in communication satellites started with ground terminals participating in transmission experiments using Echo (1960), Telstar (1962), and Relay (1963). Satellite manufacturing began with subcontracting on the Intelsat satellite developments. The first European communication satellites were the Franco-German Symphonie and the British military satellite Skynet II, both launched in 1974. Next was the Italian Sirio experiment launched in 1977. In parallel with these programs, about 15 western European nations were defining a pan-European communication satellite program. This program, managed by the European Space Agency (ESA), launched a test satellite in 1978 and improved operational satellites beginning in 1983. The operational satellites are managed by Eutelsat, an organization created for this purpose.

Through ESA, the European nations have developed a large communications satellite, Olympus. The ESA developments have provided, and are expanding, an industrial base and spacecraft technology for use on other communication and broadcasting sat-

ellite programs. These new programs include several European national satellites, all of which are now discussed, except for Skynet 4, NATO IV, and Artemis, which were described previously. European industrial teams have also competed for satellite development for non-European customers. Successes to date are Arabsat, Inmarsat II, and Orion, as well as continued subcontracting on the Intelsat developments.

Several national and multinational television broadcasting satellite projects are discussed here. In Europe, even urban areas usually have only two to three terrestrial broadcasts available, so a five-channel broadcasting satellite will more than double the number of television programs available to a nation. An additional benefit will be the ability, over much of Europe, to receive broadcasts from adjacent nations' satellites, thus further increasing the available programming. Furthermore, studies estimate the cost per net channel per year via satellite to be no more than one-fourth the cost to achieve national coverage by terrestrial means.

SYMPHONIE

The Symphonie program [1-8] was a joint effort of France and Germany, established in 1967. The primary objectives of the program were to gain technical knowledge and experience in the development of communication satellites and to perform transmission experiments. A group of six French and German companies, the CIFAS consortium (Consortium Industriel Franco-Allemand pour le Satellite Symphonie) designed and developed the satellite.

The satellite had a three-axis-stabilized hexagonal body and three solar panels that were deployed in orbit. The solar panels maintained a fixed orientation, as they had no mechanism for tracking the sun. The communication subsystem had two 90-MHz bandwidth double-conversion channels. Each channel had a tunnel diode preamplifier and a 13-W TWT transmitter. A single earth coverage horn was used for reception. Two elliptical reflectors with off-axis feeds were used for transmission. Each reflector reduced an 8- × 13-deg beam. One TWT was connected to each transmitting antenna, and a switch allowed reversal of these connections. The satellites were designed to be stationed over the Atlantic Ocean, with one transmitting antenna covering most of Europe and Africa and the other covering the eastern United States and Canada and part of South America. Other satellite details are as follows:

Satellite

Hexagonal body, 68-in. maximum dia., 20-in. height, 23-ft dia. with solar panels deployed

38 lb in orbit, beginning of life

Solar cells and NiCd batteries, 300 W initially, 180 W minimum after five years (batteries did not support the communication subsystem during eclipse)

Three-axis stabilization, 0.5-deg attitude control accuracy

Separate bipropellant liquid propulsion subsystems for apogee maneuver and on-orbit use

Configuration

Two 90-MHz bandwidth double-conversion repeaters

Capacity

600 one-way voice circuits or one color TV signal with three voice channels per repeater

Transmitter

3715 to 3805 MHz and 3970 to 4060 MHz (Satellite 2)

3840 to 3930 MHz and 4095 to 4185 MHz (Satellite 1)

13-W TWT per channel (no redundancy)

29-dBW minimum ERP per channel over 8- × 13-deg field of view, 30 dBW typical

Receiver

5940 to 6030 MHz and 6195 to 6285 MHz (Satellite 2)

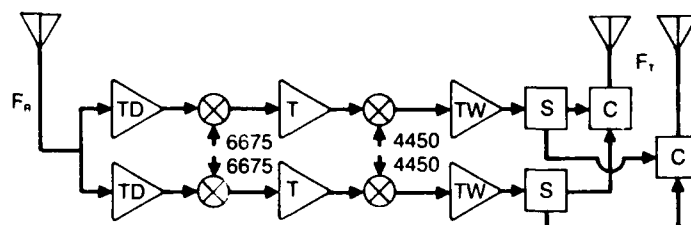
6065 to 6155 MHz and 6320 to 6410 MHz (Satellite 1)

Tunnel diode preamplifier, approximately 7.5-dB noise figure

-15 dB/K G/T minimum over 17-deg field of view, actual performance -14 dB/K or better

Antenna

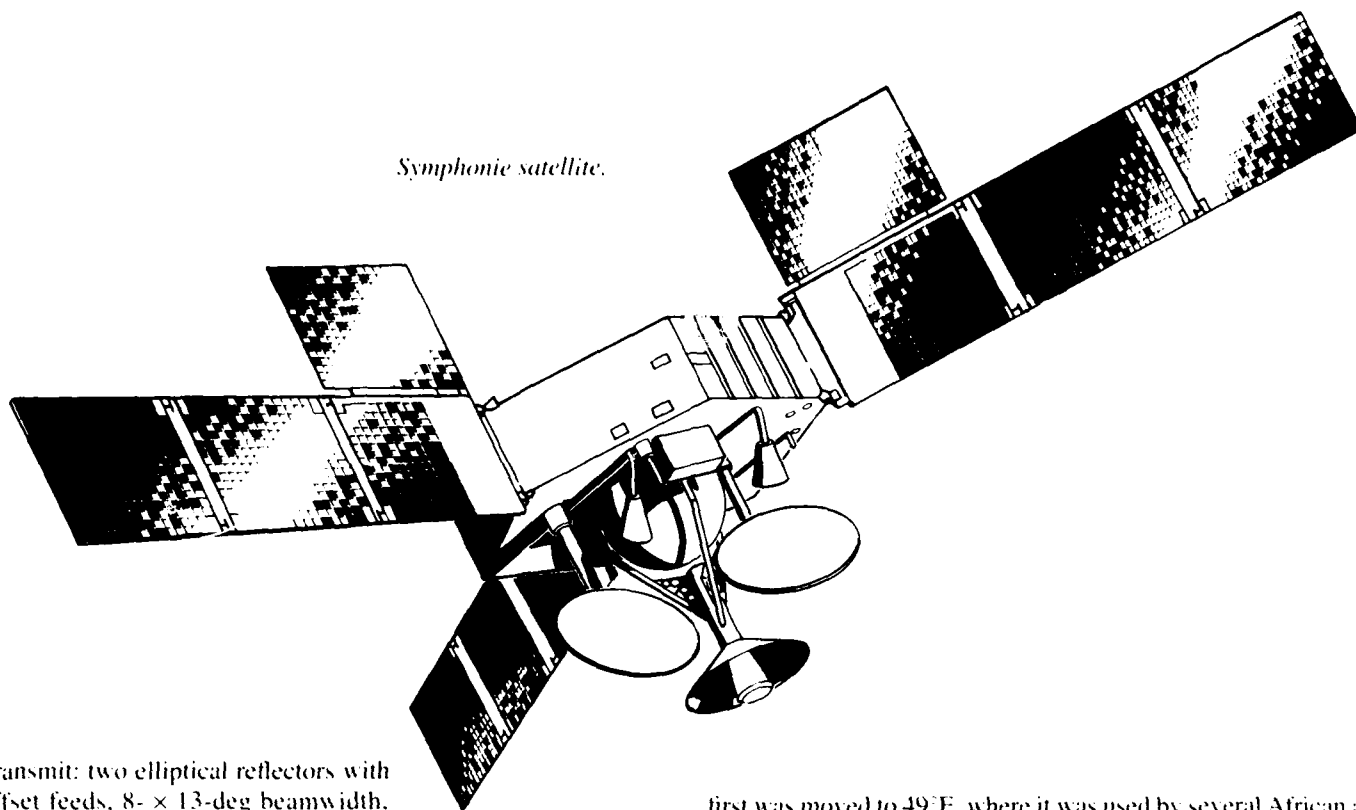
Receive: earth coverage horn, 17.2-deg beamwidth, circular polarization



	Satellite 1	Satellite 2
Receive frequencies (F_R):	6065-6155 6320-6410	5940-6030 6195-6285
Transmit frequencies (F_T):	3840-3930 4095-4185	3714-3805 3970-4060

Symphonie communication subsystem.

Symphonie satellite.



Transmit: two elliptical reflectors with offset feeds, $8^\circ \times 13^\circ$ -deg beamwidth, circular polarization

Design life

Five years

Orbit

Synchronous equatorial, 11.5° W longitude, stationkeeping to $\pm 0.5^\circ$ N-S and E-W

Satellite 1 was moved to 49° E longitude during 1976, then returned to 11.5° W a few years later

Orbital history

1: launched 18 December 1974, turned off in 1984 or 1985 and moved out of synchronous orbit

2: launched 27 August 1975, turned off in 1984 or 1985 and moved out of synchronous orbit

Delta 2914 launch vehicle

Management

Developed by CIEAS, a French-German industrial consortium, for Centre National d'Etudes Spatiales (CNES)—French Space Agency, and Deutsche Forschungs und Versuchsanstalt für Luft und Raumfahrt (DFVLR)—German Space Agency

The Symphonie system was planned for two operating satellites in orbit. Transmitting and receiving frequencies of these two satellites were not identical but interleaved, and thus the two satellites could be placed very close to each other in orbit without mutual interference. To ground terminals, they appeared to be a single satellite with four channels.

Original plans were for the launches from Kourou, French Guiana, using the Europa II launch vehicle. However, since the Europa program was cancelled, the Symphonies were launched by the United States on a Delta launcher. The first Symphonie launch occurred in December 1974, and the second launch was in August 1975. Initially, both satellites were at 11.5° W longitude and were used for a variety of communication links. In 1976, the

first was moved to 49° E, where it was used by several African and Asian countries for experimental programs. A few years later, it was returned to approximately 11.5° W. The Symphonie satellites were replaced by the Telecom 1 satellites.

* * * * *

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EUROPEAN SPACE AGENCY

The European Space Agency (ESA) [1-10] was formed in May '75 by a merger of the European Space Research Organization (ESRO) and the European Launcher Development Organization. It has thirteen member nations and one associate member. All nations do not participate in every program, but most programs are supported by at least eight nations. Each nation's contributions to an ESA program may vary from about 1 to 60% of total program cost—Great Britain, Germany, and France are the largest contributors. It is normal for the contracted work on an ESA project to be distributed among the countries in proportions closely matched to their contributions. This results in more complicated industrial teaming arrangements than exist in the United States, which contributes to greater management complexity and higher overhead costs [2]. However, teaming arrangements for commercial projects are simpler.

The ESA has several communication satellite projects. The first was the Orbital Test Satellite (OTS), which was a preoperational test for a European regional communication system. The operational satellites were called the European Communication Satellite (ECS) series and have evolved into the Eutelsat system. Olympus is a derivative of ECS and is designed for communication with ships. Olympus is a newer program with many communications and spacecraft technology demonstrations. ESA is also preparing for a Data Relay Satellite program.

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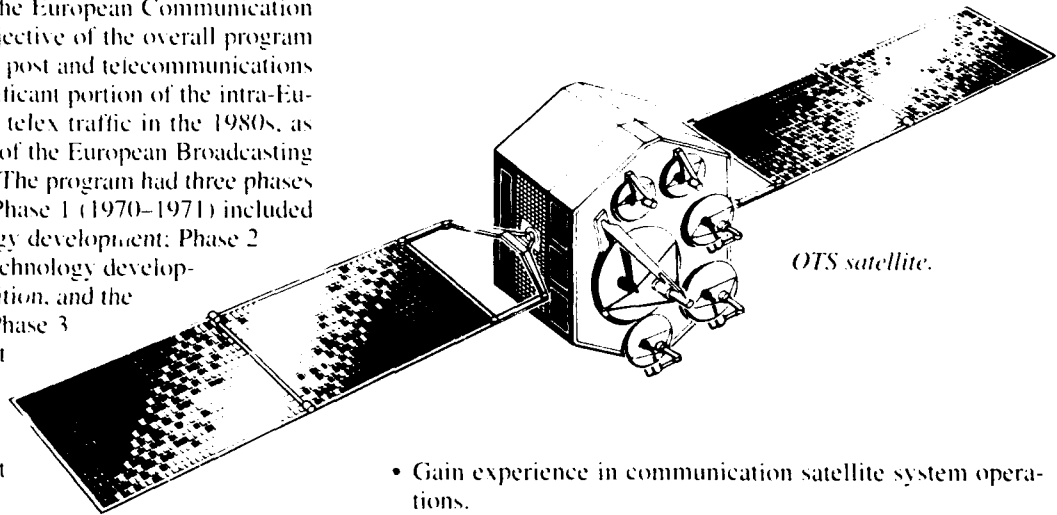
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OTS

The OTS [1-25] was a part of the European Communication Satellite Program. The primary objective of the overall program is to make available to European post and telecommunications authorities satellite links for a significant portion of the intra-European telephone, telegraphy, and telex traffic in the 1980s, as well as to satisfy the requirements of the European Broadcasting Union (EBU) for Eurovision relay. The program had three phases leading to an operational system: Phase 1 (1970-1971) included system studies and initial technology development; Phase 2 (1972-1977) included additional technology development, communication system definition, and the development and launch of OTS; Phase 3 (1977-1980) was the procurement and launch of operational satellites. (After the plan was formulated, Phase 2 slipped out one year and Phase 3 about 6 years.)

OTS was basically experimental in nature but was designed with a configuration similar to that expected for the operational satellites. The objectives of the OTS program were to

- Demonstrate the performance and reliability of the satellite subsystems.
- Demonstrate the proposed operational capabilities and provide the capacity for preoperational transmissions.



OTS satellite.

- Gain experience in communication satellite system operations.
- Perform propagation measurements at 11 and 14 GHz.

The satellite was three-axis-stabilized with two solar arrays that deployed after synchronous orbit had been achieved. The solar arrays rotated about their axes to track the sun. The main body of the satellite was a hexagonal prism with a maximum diameter of about 7 ft. The six communications antennas were mounted on the earth-viewing end of the satellite body. The OTS characteristics are summarized as follows:

Satellite

Hexagonal prism body, 85-in. dia., 77-in. height, 28.3 ft tip to tip of deployed solar arrays

955 lb in orbit, beginning of life

Sun-tracking solar array and NiCd batteries, 750 W initially, 555 W minimum after three years

Three-axis stabilization, ± 0.17 deg (pitch and roll), ± 0.5 deg (yaw), 3σ , nominal 0.2-deg antenna pointing accuracy

Solid rocket motor for apogee maneuver, liquid hydrazine propulsion for on-orbit use

Configuration

Six double-conversion repeaters (two 40-MHz, two 120-MHz, two 5-MHz bandwidth), dual-polarization frequency reuse

Transmitter

11,490 to 11,530 MHz (two 40-MHz channels on orthogonal polarizations)

11,580 to 11,700 MHz (two 120-MHz channels on orthogonal polarizations)

11,792.5 to 11,797.5 MHz (two 5-MHz channels on orthogonal polarizations)

One 20-W TWT per repeater, plus two redundant TWTs

Peak ERP per repeater: 38.5 dBW (40-MHz repeaters), 47.5 dBW (120-MHz repeaters), 41.1 dBW (5-MHz repeater)

Receiver

14,152.5 to 14,192.5 MHz (two 40-MHz channels on orthogonal polarizations)

14,242.5 to 14,362.5 MHz (two 120-MHz channels on orthogonal polarizations)

14,455 to 14,460 MHz (two 5-MHz channels on orthogonal polarizations)

Two receivers (one on, one standby) per polarization (40- and 120-MHz channels)

One receiver per polarization (5-MHz channels)

Parametric amplifier

1000-K system noise temperature

Peak G/T: -3.6 dB/K (40- and 120-MHz channels), -1.0 dB/K (5-MHz channels)

Antenna

Three Eurobeam A (two receive, one transmit), 4.25×7.5 deg at -3 dB contour, approximately 26.5-dB peak gain, linear polarization

Two Eurobeam B (one receive, one transmit), 3.5×5 deg at -3 dB contour, approximately 29.1-dB peak gain, circular polarization

One spot beam (transmit), 2.5 deg at -3 dB contour, approximately 35.5-dB peak gain, linear polarization

(Gains are measured at input to receive filter or output of transmit filter)

Design life

Three years

Orbit

Synchronous equatorial, was 10° E longitude, moved to 5° E longitude in 1982, stationkeeping to $\pm 0.1^\circ$ N-S and E-W

Orbital history

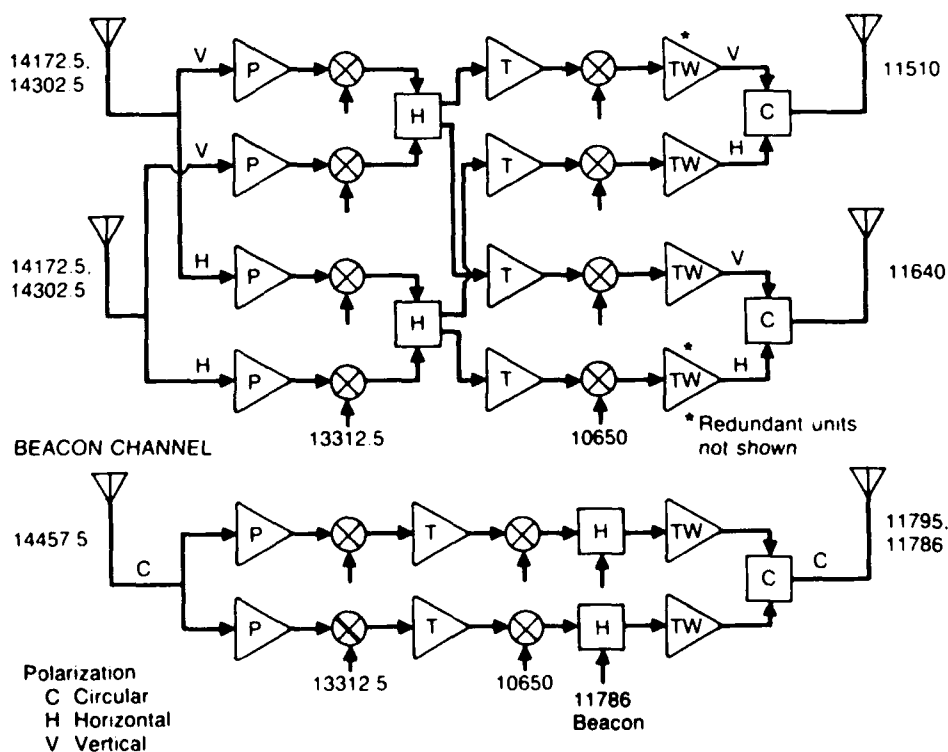
1: launch vehicle failure, 13 September 1977

2: launched 11 May 1978, in regular use until the end of 1983, used in tests for several more years, later moved above synchronous orbit

Delta 3914 launch vehicle

OTS communication subsystem.

COMMUNICATION CHANNELS



Management

Developed by Hawker Siddeley Dynamics (now British Aerospace Dynamics Group), prime contractor for MESH (a west European industrial consortium) for ESA

Operated by ESA

The OTS communication subsystem had characteristics identical to those planned for operational satellites, except for a reduced number of channels. During the time of the OTS design, the operational satellites were expected to have six 40-MHz and six 120-MHz channels grouped in pairs with the two channels of each pair sharing the same frequencies by means of orthogonal polarizations. OTS had one pair of 40-MHz channels and one pair of 120-MHz channels. In addition, there was a pair of 5-MHz beacon channels.

The communication channels used orthogonal linear polarizations with redundant dual-polarization receiving antennas. These antennas were connected to redundant wideband receivers that had parametric amplifier front ends. After the receivers, the four channels were separated and each passed through separate filters, IF amplifiers, upconverters, and 20-W TWTs. The two 40-MHz channels were transmitted by a single antenna that radiated dual orthogonal linear polarizations. The 120-MHz channels shared a single dual-polarization transmit antenna that had a narrower beamwidth.

The beacon transponder had separate receiving and transmitting antennas, each accommodating both orthogonal circular polarizations. The transponder had two complete parallel sets of equipment that could be operated simultaneously, with each channel associated with one polarization. The transponder also generated and transmitted an unmodulated beacon at a frequency below the 5-MHz repeater band.

The 40- and 120-MHz channels were both used for telephony transmissions with QPSK modulation and TDMA. The 40-MHz channels were also used for frequency-modulated television signals. The receiving antennas for all of these channels and the transmitting antenna for the 40-MHz channels had beamwidths

covering all of Europe plus a portion of North Africa. This was the Eurobeam A coverage shown in the European ground terminal sites figure. This coverage was required, because the EBU must serve points as widely separated as Iceland, the Azores, and Israel. The 120-MHz channels used a spot-beam transmitting antenna with a 2.5-deg beamwidth, which included the terminals handling about 85% of the telephony traffic. The beacon channel used antennas with an intermediate beamwidth (Eurobeam B in the figure). This channel was used for propagation measurements and experimental transmissions by small terminals, e.g., an antenna diameter of approximately 10 ft. More than thirty ground terminal sites (generally only one per country) expected in the operational system are shown; a few were built in time to participate in OTS testing.

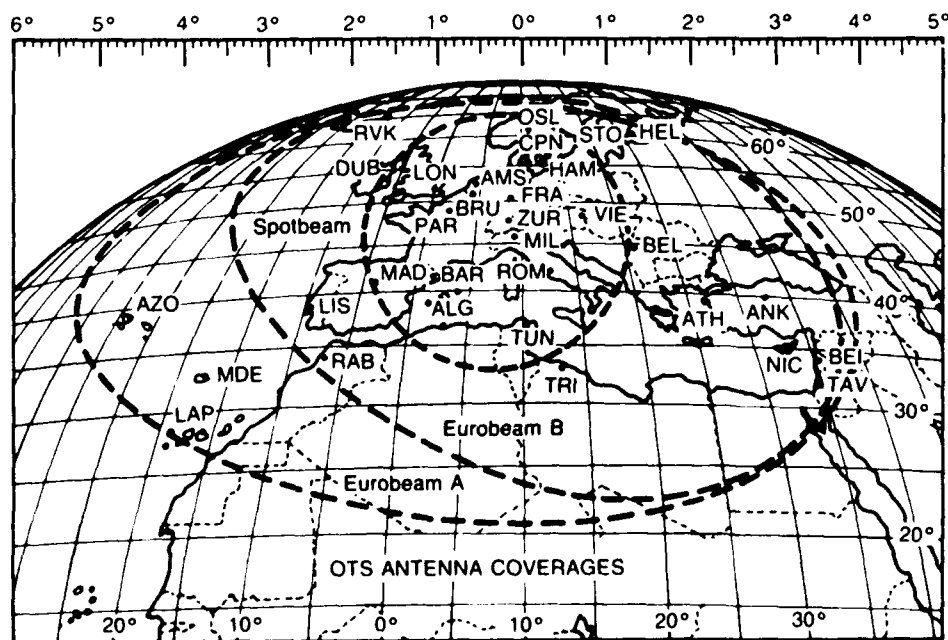
When the final design of OTS was started in 1974, the satellite was sized for a Delta 2914 launch vehicle. Later, it was redesigned to take advantage of the larger capacity of the Delta 3914. In the payload, the redesign consisted of the addition of the extra TWTs in the wideband channels and the addition of the second beacon channel. The first launch, in September 1977, was unsuccessful, because the launch vehicle exploded shortly after liftoff. A spare satellite was successfully launched in May 1978. This satellite was used through late 1984 beyond its design life.

* * * * *

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Marecs

The Marots (Maritime Orbital Test Satellite) program [1-14] was approved in 1973 with the objective to obtain experimental data and preoperational experience in the maritime satellite environment. The program included communications tests and evaluation of operational techniques and ship terminals of various designs. The basic characteristics of the system were consistent with the available guidelines for future operational systems.

The Marots satellite design was based on the OTS design, and the development of the two satellites overlapped in several aspects such as personnel, components, and testing. The Marots mission was basically experimental; during its development, however, international discussions were proceeding on the deployment of an operational, global maritime system. In 1976, ESA offered Marots for use as part of an interim global system. As a result of many discussions with potential major participants in an international system, several changes were made in the Marots design. These changes caused a significant delay in the development program and, as a result, ESA decided to switch from an OTS-type spacecraft to the more capable ECS spacecraft. There-

fore, the name of the satellite was changed to Marecs (Maritime European Communication Satellite) [15-23]. Also, the emphasis of its use was changed from experimental to operational. The satellite details are as follows:

Satellite

Hexagonal prism body, 86-in. dia., 77-in. height; 45 ft tip to tip of deployed solar arrays, overall height approximately 100 in.

1260 lb in orbit, beginning of life

Sun-tracking solar array and NiCd batteries, 955 W beginning of life, 790 W end of life

Three-axis stabilization, antenna pointing accuracy ± 0.2 deg (pitch and roll), ± 0.35 deg (yaw)

Solid rocket motor for apogee maneuver, liquid hydrazine propulsion for on-orbit use

Configuration

Three repeaters: 4.75-MHz bandwidth for shore-to-ship, 5.9-MHz bandwidth for ship-to-shore, 0.5-MHz for shore-to-shore

Capacity

Thirty-five voice channels each direction plus search-and-rescue channel in ship-to-shore direction

Transmitter

4194.6 to 4200.5 MHz (to shore), 1-W TWT plus spare, ERP 16.6 dBW measured, 14.5 dBW specified

1537.75 to 1542.5 MHz (to ships); ten transistor amplifiers available, up to six can be on, maximum output 75 W; minimum measured ERP over coverage area is ≥ 35 dBW

Receiver

6420.25 to 6425 MHz (from shore), G/T -12 to -13 dB/K measured, -17 dB/K specified

1638.6 to 1644.5 MHz (from ships), G/T -11 dB/K minimum measured over coverage area

Antenna

One L-band (1500- to 1700-MHz) parabolic antenna, 80-in. dia., beam shaped to give 1.4 dB more gain at edge of coverage than on axis

Two horns (one transmit, one receive) for 4 and 6 GHz

All antennas are earth coverage

Design life

Seven years

Orbit

Synchronous equatorial (inclination < 3 deg), stationkeeping to ± 0.2 E-W

Orbital history

A: launched 20 December 1981, 26° W longitude, 178° E longitude from 1986, in use until June 1991

B: launch failure, September 1982

B2: launched 10 November 1984, 177.5° E longitude, 26° W longitude from 1986 to 1989, 56° W longitude from 1990, in use

Ariane launch vehicle

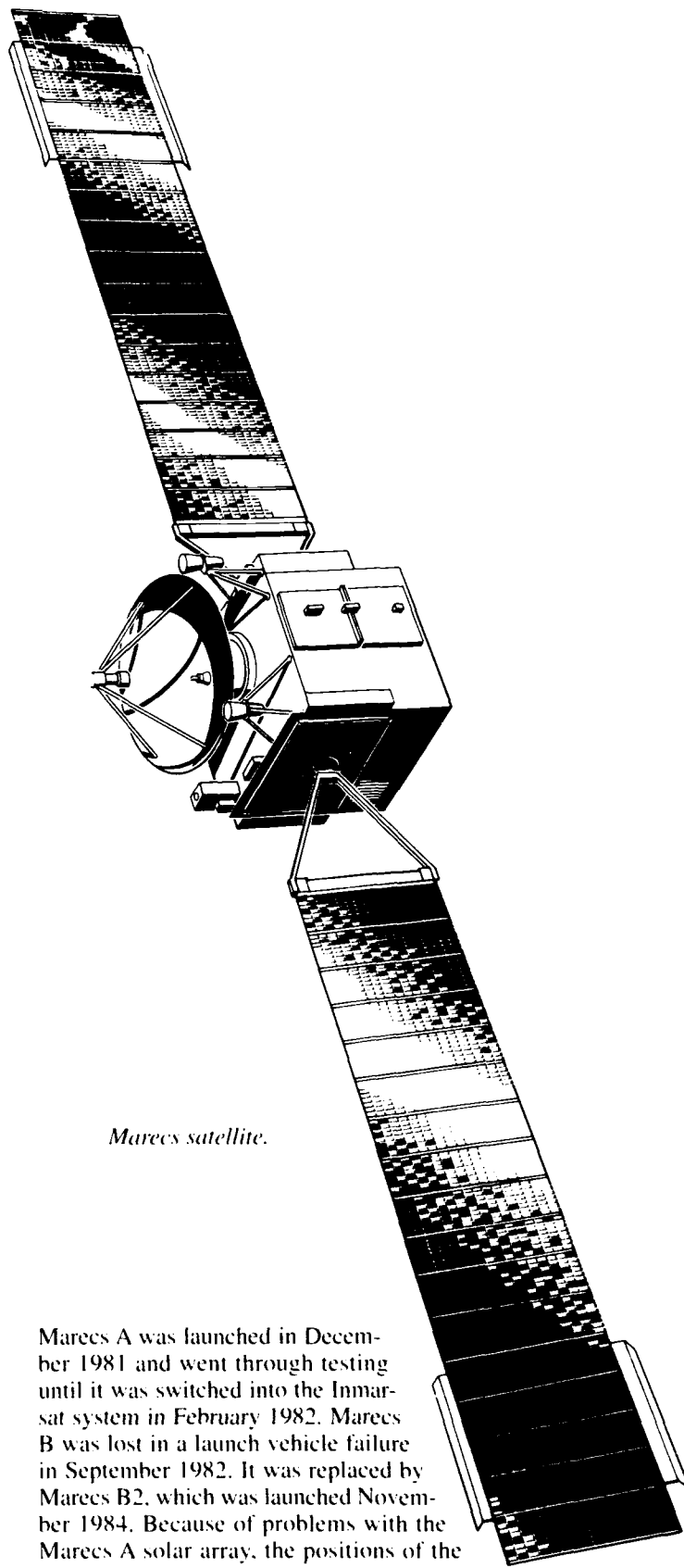
Management

Developed by MESH consortium (prime contractor, Hawker-Siddeley Dynamics, now British Aerospace Dynamics Group) for ESA

Operated by ESA for Inmarsat

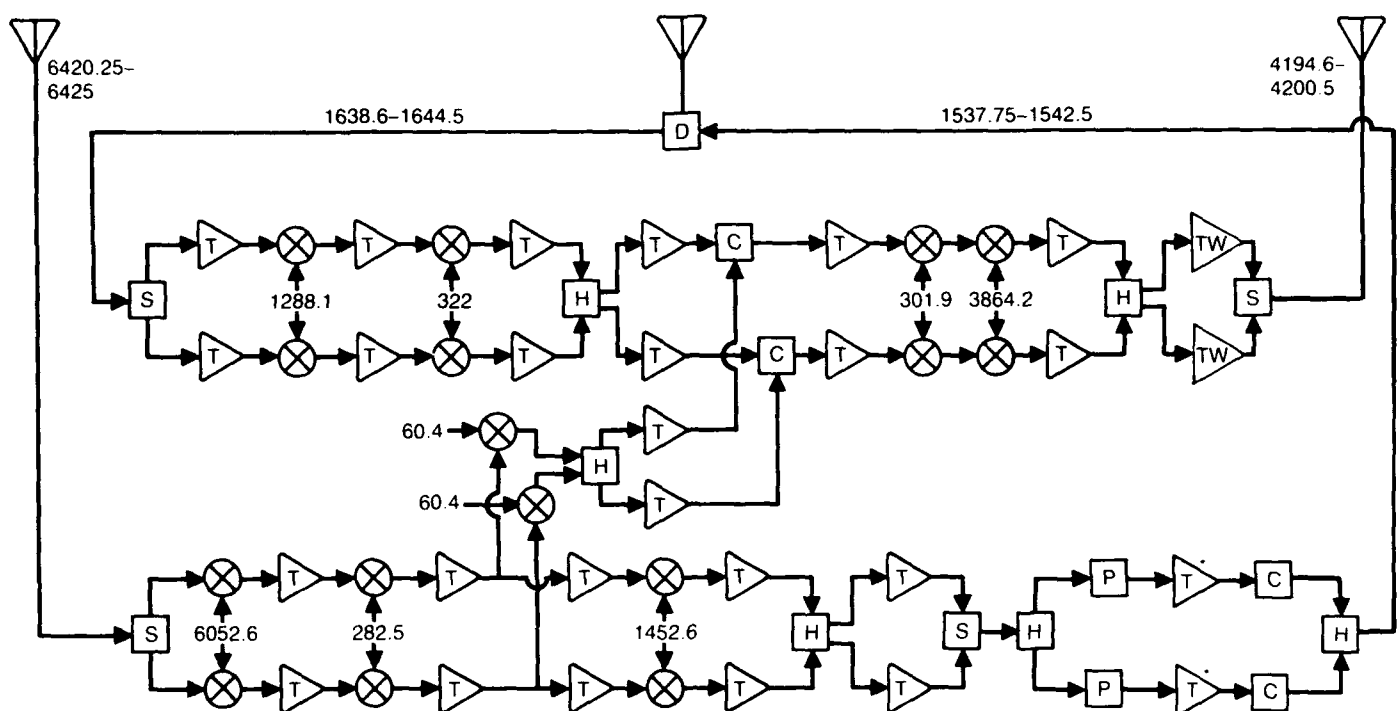
The communication subsystem of Marecs has three channels. The forward channel (shore-to-ship) has a 5-MHz bandwidth and the return channel has a 6-MHz bandwidth. A shore-to-shore channel for network coordination has a 0.5-MHz bandwidth. All links with ships use L-band, and all links with shore stations use 4 and 6 GHz. The return channel provides up to fifty voice channels at all times. The forward channel handles up to about forty voice channels, depending on the ship terminal G/T, except during eclipse when the capacity is less than ten channels. All amplifiers are operated in a near-linear state, so that FDMA operation can be used with acceptable intermodulation levels. The L-band power amplifier is composed of ten parallel modules in two groups of five; in normal operations, three modules in each group are active.

The Marecs development program included two flight model satellites. Discussions on the role of Marecs in the Inmarsat system continued from about 1978 to 1981, when Inmarsat decided to include two Marecs in its first-generation space segment.



Marecs satellite.

Marecs A was launched in December 1981 and went through testing until it was switched into the Inmarsat system in February 1982. Marecs B was lost in a launch vehicle failure in September 1982. It was replaced by Marecs B2, which was launched November 1984. Because of problems with the Marecs A solar array, the positions of the two satellites were switched in 1986, thus placing Marecs B2 in the Atlantic area, where Inmarsat traffic is heaviest. Continuing solar array degradation caused Marecs A to be removed from service in 1991, after exceeding its design life by two and one-half years.



Marecs communication subsystem.

* Five amplifiers in parallel in each side

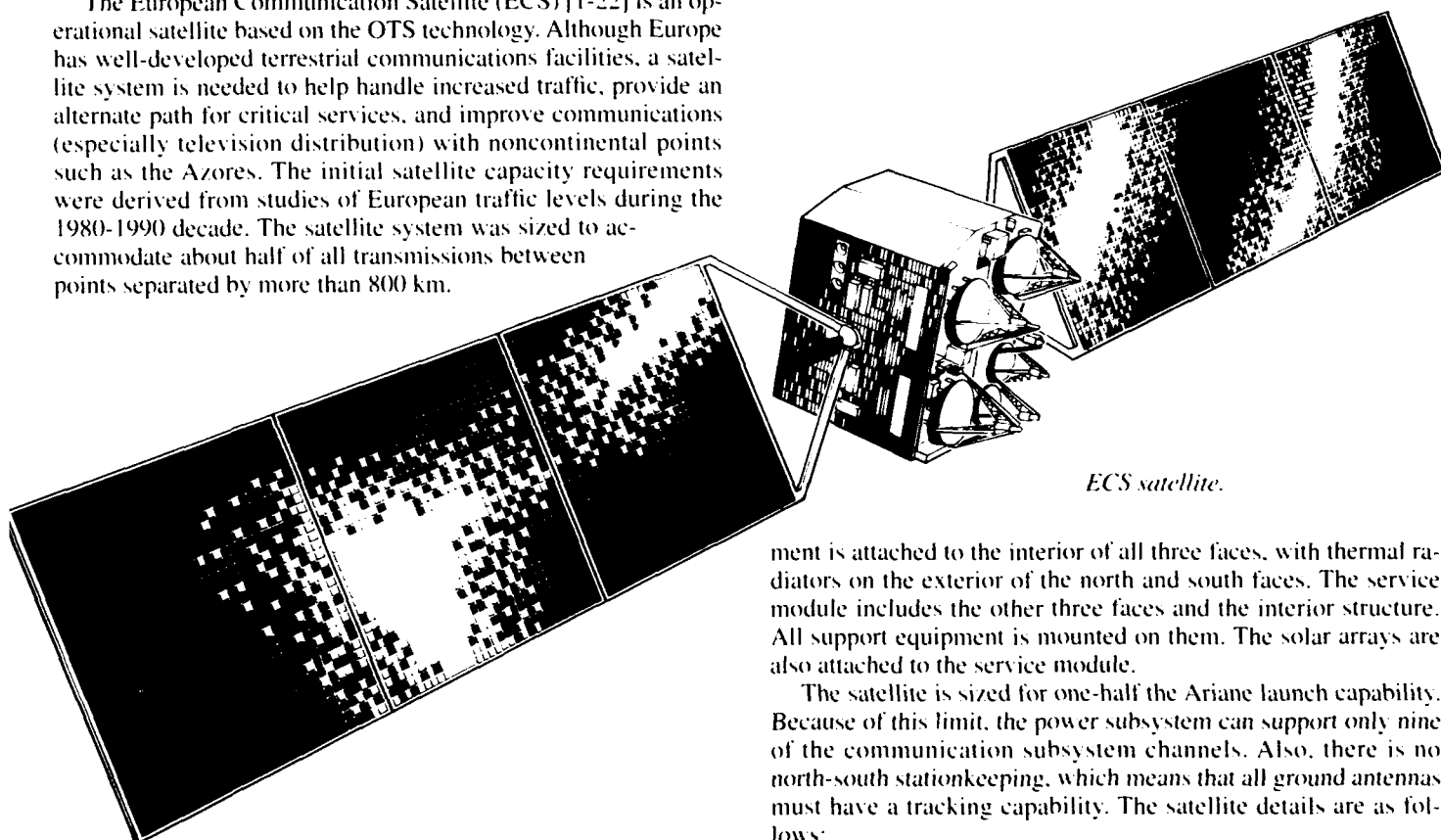
In 1990, Inmarsat split their Atlantic area into two areas, in order to increase services, and Marecs B2 was moved to become the primary west Atlantic satellite. Additional information on the use of these satellites is in the Inmarsat systems section earlier in this document.

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European Communications Satellite/Eutelsat I

The European Communication Satellite (ECS) [1-22] is an operational satellite based on the OTS technology. Although Europe has well-developed terrestrial communications facilities, a satellite system is needed to help handle increased traffic, provide an alternate path for critical services, and improve communications (especially television distribution) with noncontinental points such as the Azores. The initial satellite capacity requirements were derived from studies of European traffic levels during the 1980-1990 decade. The satellite system was sized to accommodate about half of all transmissions between points separated by more than 800 km.



ECS satellite.

The OTS/ECS program started in the early 1970s with the development of a baseline design for ECS. The purpose of the study was to determine what technology should be tested on the OTS for ECS. Since then, the ECS design has been reconsidered several times; the present design uses 80-MHz bandwidth transponders rather than the 40- and 120-MHz combination used in OTS. Also, ECS has three spot beams rather than the one used on OTS. However, even with these design differences, all OTS developments are applicable to ECS.

ECS is a three-axis-stabilized satellite with sun-tracking solar arrays. It is composed of a service module and a communication module. The communication module includes the earth-viewing, north, and south faces of the body. The antennas are all fixed on the exterior of the earth-viewing face. Communications equip-

ment is attached to the interior of all three faces, with thermal radiators on the exterior of the north and south faces. The service module includes the other three faces and the interior structure. All support equipment is mounted on them. The solar arrays are also attached to the service module.

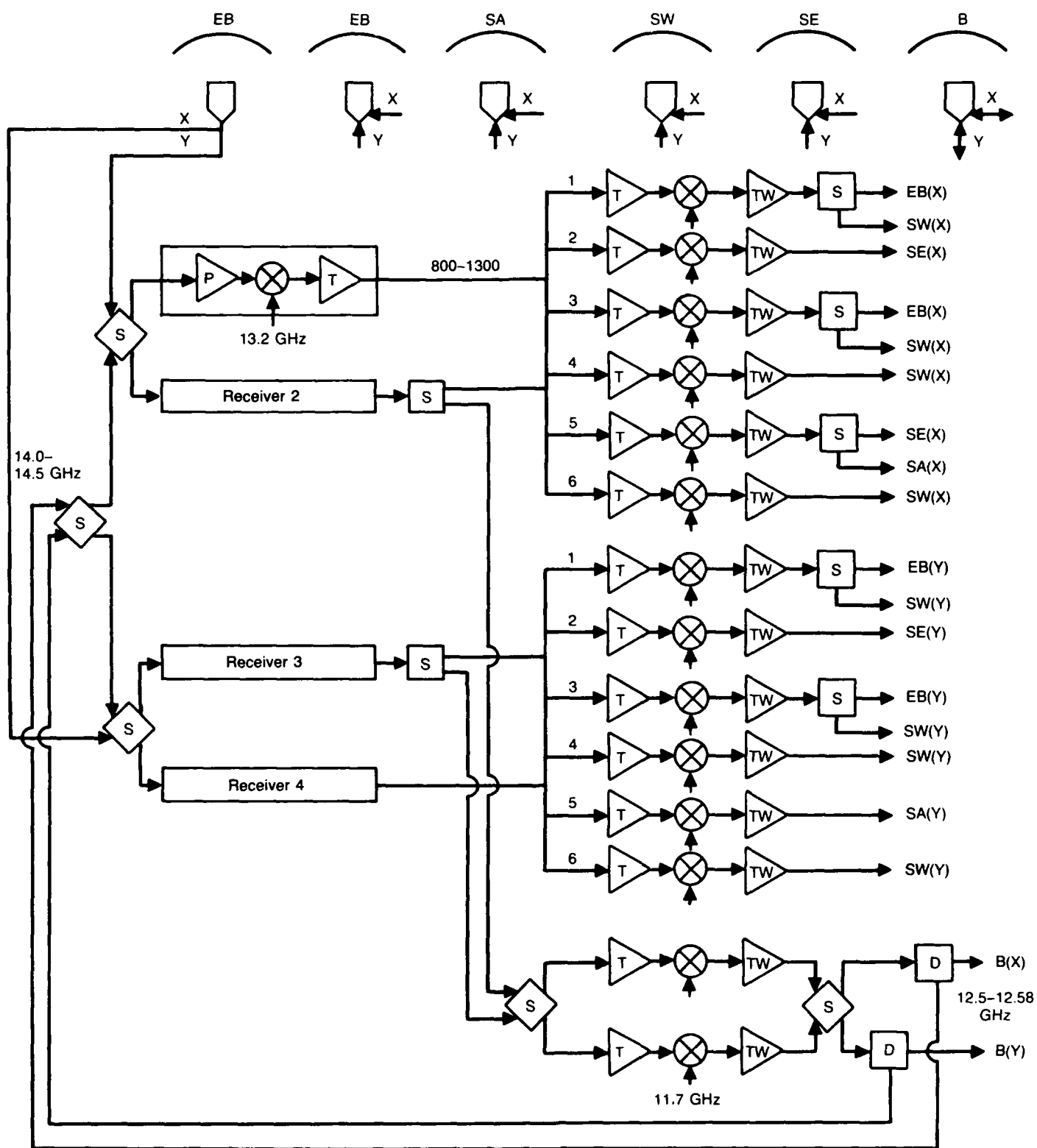
The satellite is sized for one-half the Ariane launch capability. Because of this limit, the power subsystem can support only nine of the communication subsystem channels. Also, there is no north-south stationkeeping, which means that all ground antennas must have a tracking capability. The satellite details are as follows:

Satellite

Main body maximum dia. 7 ft, deployed solar arrays span 45 ft
 1342 (ESC 1)/1496 (ESC 2-5) lb in orbit, beginning of life
 Solar cells and NiCd batteries, 1120 W at beginning of life, 920 W minimum after seven years
 Three-axis stabilization, 0.2-deg antenna pointing accuracy
 Solid rocket motor for apogee maneuver, liquid hydrazine propulsion for on-orbit use

Configuration

Twelve 72-MHz bandwidth receive channels, twelve (ECS 1)/14 (ECS 2-5) transmit channels, double conversion; solar array can power a maximum of nine channels, batteries can power a maximum of five (ECS 1)/nine (ECS 2-5) channels during eclipse; dual-polarization frequency reuse



Notes

- LO input to Channel 1–3 is 9.9 GHz
- LO input to Channel 4–6 is 10.65 GHz
- EB = Eurobeam
SA = Spot Atlantic
SW = Spot West
SE = Spot East
B = Business Service
- X, Y = linear polarizations

- No business service channels on ECS 1
- Channels 1–3 transmit in 10.95–11.2 GHz band
- Channels 4–6 transmit in 11.45–11.7 GHz band
- No channel 4 use when business channels are in use.

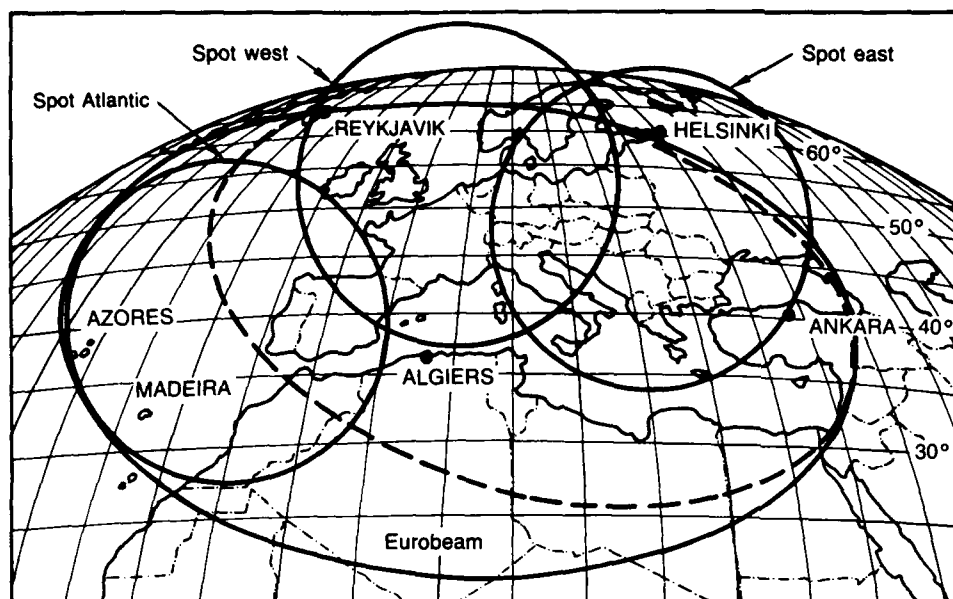
ECS communication subsystem.

Capacity

1800 telephone calls (120 Mbps TDMA rate), or one TV signal with multiple audio channels, or 400 64-kbps links to small terminals per channel

Transmitter

10.95 to 11.20 GHz and 11.45 to 11.70 GHz (primary services)



ECS antenna patterns.

12.50 to 12.58 GHz (business services, ECS 2-5; also called satellite multiservices)

One 20-W TWT per channel (no spares)

ERP at edge of coverage: 34.8 dBW (Eurobeam), 40.8 dBW (spot beams), 39.8 dBW (business service beam)

Receiver

14.0 to 14.5 GHz

G/T at edge of coverage: -5.3 dB/K (Eurobeam), -2.2 dB/K (business service beam)

Antenna

Three 24-in.-dia. parabolas, each producing one 3.7-deg transmit spot beam; one 17-in.-dia. parabola (ECS 1)/one offset-fed toroidal reflector (ECS 2-5), producing a 5.2- × 8.9-deg transmit Eurobeam; two 13-in.-dia. parabolas (ECS 1)/two offset-fed toroidal reflectors (ECS 2-5), producing two 5.2- × 8.9-deg receive Eurobeams (ECS 1)/one receive Eurobeam and one diplexed business services beam (ECS 2-5); all antennas support orthogonal linear polarizations with 23-dB cross-polarization isolation

Design life

Seven years

Orbit

Synchronous equatorial, inclination ≤ 3.5 deg, E-W stationkeeping to ± 0.1 deg

Orbital history

- 1: launched 16 June 1983, 16°E longitude, in use
 - 2: launched 4 August 1984, 11°E longitude, in use
 - 3: launch vehicle failure, September 1985
 - 4: launched 15 September 1987, 13°E longitude, in use
 - 5: launched 21 July 1988, 40°E longitude, in use
- Ariane launch vehicle

Management

Developed by the MESH consortium (prime contractor British Aerospace Dynamics) for ESA acting for Eutelsat

Operated by ESA acting for Eutelsat

The basic communication subsystem design has twelve channels. Each polarization has six channels with 83.3-MHz center-to-center spacing, which fills the 500-MHz allocation at 11 GHz (downlink) and 14 GHz (uplink). Beginning with the second ECS, an additional pair of downlink channels was added at 12.5 GHz for business services, also called satellite multiservices. One pair of uplink channels may be switched between these additional downlink channels and two of the basic downlink channels.

ECS has four antenna patterns. The Eurobeam is used for both reception and transmission and covers the entire area which ECS must serve. The three spot beams are for transmission only. The two business services channels have a receive and transmit beam pattern slightly smaller than the dashed ellipse shown in the figure. Five of the twelve basic channels are permanently connected to spot beams. The other seven are each switchable between two transmit antennas. The largest number of channels may be connected to the west spot, which covers the cities that account for about 80% of the telephony traffic.

The ECS satellites, now called the Eutelsat I satellites, are managed by Eutelsat, a commercial organization formed by an intergovernmental agreement. ESA handles the construction, launching, and in-orbit control of ECS for Eutelsat. The first two satellites were ordered in 1979, and the next three in 1980. The first two satellites were launched in 1983 and 1984. The third was lost in a launch vehicle in 1985. The last two were launched in 1987 and 1988.

All four satellites have been kept in use by Eutelsat. Their roles and locations, within the 7 to 16°E longitude favored by Eutelsat, have varied over the years. By the beginning of 1991, the first Eutelsat I had no more fuel for north-south stationkeeping, and its inclination was beginning to increase. Nevertheless, it is still being used by large ground antennas which can track its motion. The majority of Eutelsat traffic is on the other three satellites. Further changes in traffic and orbital locations will occur in 1991 as the Eutelsat II satellites come into operation. Additional information on the use of these satellites is in the Eutelsat Systems section.

* * * * *

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Olympus

The Olympus satellite [1-24] development began in 1982. Former program names include Large Telecommunication Satellite (L-Sat), Heavy Telecommunications Satellite (H-Sat), and Phebus. The use of large or heavy in the earlier program names was because the satellite is about twice the size of ECS. The program direction was guided by several studies of future communication satellite needs, and how European industry could respond to the opportunities to satisfy these needs. The objectives of the program are (1) to develop and demonstrate a large satellite platform, and (2) to develop communications hardware for and provide an orbital demonstration of several new communications services.

The Olympus spacecraft is designed to be adaptable to a variety of payloads within the following payload limits: 6.5-kW power demand in sunlight, 3 kW in eclipse, 1300 lb including antennas. In addition, the spacecraft must be able to provide adequate space for payload mounting (especially multiple antennas) and thermal radiators. Another Olympus requirement was compatibility with both Ariane and Shuttle launches.

Many aspects of the Olympus design—structural strength, solar array mechanisms, and thermal control—are sized for the maximum payload capacity rather than for the requirements of the present payload. Future uses of the spacecraft will look the same except for a new set of antennas and a possible change in

solar array length. The north and south panels of the spacecraft primarily support payload equipment on the inside and thermal radiators on the outside. The east, west, and back (i.e., anti-earth side) panels, together with a central cylinder, which is the primary structure, support propulsion, power, TT&C, and control subsystems. Deployable antennas are mounted on the east and west panels. Other antennas, as well as the remaining payload hardware, are mounted on the earth-viewing face. The solar cells are mounted on a flexible blanket; the arrays are deployed in orbit using a telescoping mast. The propulsion subsystem is a liquid bi-propellant type and is used for both the apogee maneuver and on-orbit control. Spacecraft and payload details are as follows:

Satellite

Rectangular body $69 \times 83 \times 120$ in., height of body plus antennas approximately 200 in., span of solar array approximately 86 ft

Approximately 3000 lb in orbit, beginning of life

Sun-tracking solar arrays and NiCd and NiH_2 batteries, approximately 3500 W beginning of life

Three-axis stabilization using reaction wheels on three orthogonal axes

Unified bipropellant propulsion for apogee maneuver and on-orbit use

Configuration

TV broadcast payload (TVB): three 27-MHz bandwidth channels, two of which are used at a time

Business services payload (BSP), also called specialized services payload: four 18-MHz bandwidth channels, or one or two may be switched to 30 MHz, satellite switched TDMA, and frequency re-use

20/30 GHz communications payload (COM): two 40-MHz bandwidth channels, or one 700-MHz bandwidth channel

20/30 GHz propagation payload (PROP): beacons at 12.5, 19.77, and 29.66 GHz

Transmitter

TVB: 12.169 GHz (beam 1) and 12.092 or 12.245 GHz (beam 2) (ITU broadcasting satellite channels 24, 20, 28)

Four 230-W (215 W end of life) TWTs, one on plus one spare per beam

Peak ERP 62.4 dBW (beam 1), 62.7 dBW (beam 2)

BSP: 12.525 and 12.550 GHz (18-MHz channels), 12.530 and 12.570 GHz (30-MHz channels)

Four 30-W TWTs

45.6-dBW ERP at edge of coverage

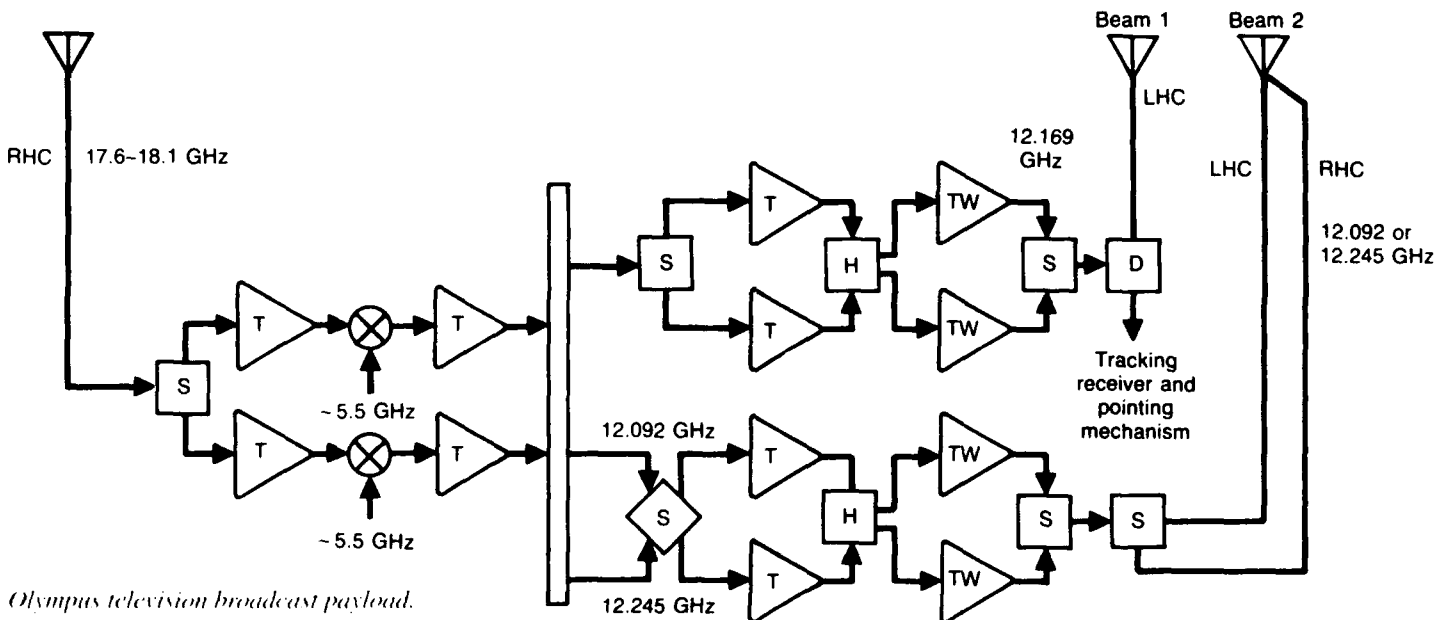
COM: in 18.8- to 19.5-GHz band

Three 30-W TWTs, two on plus one spare

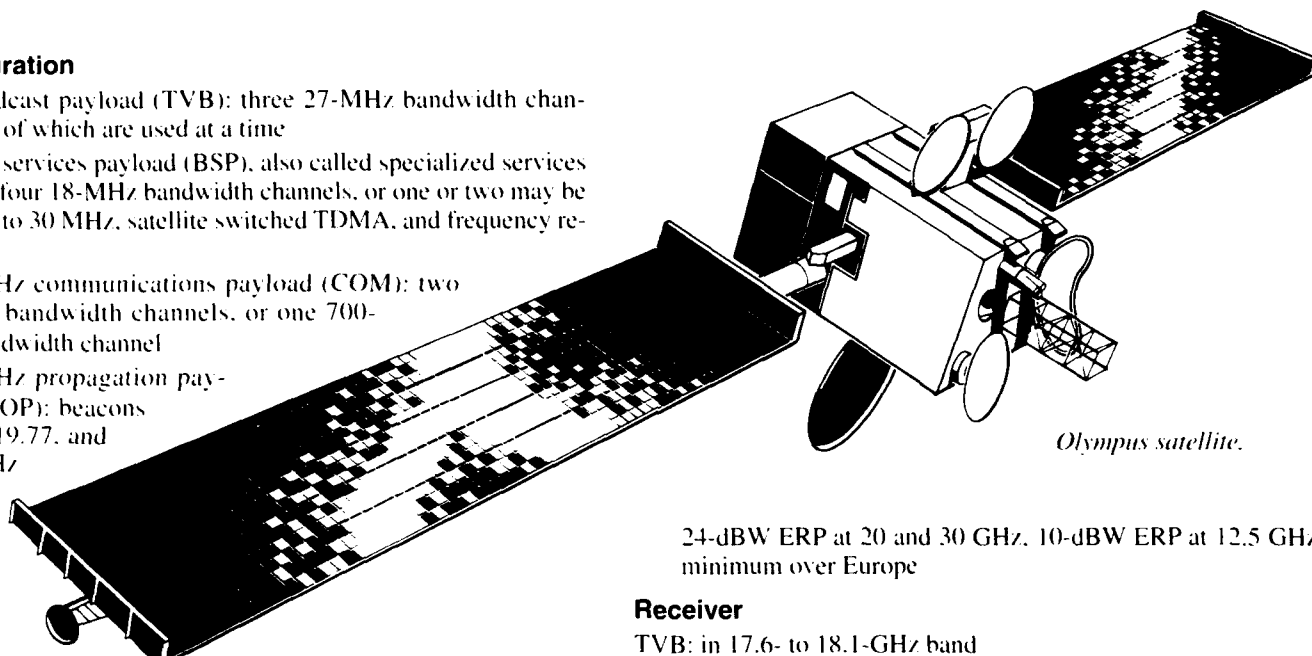
52-dBW ERP at edge of coverage

PROP: 12.5, 19.77, and 29.66 GHz

Two 10-W TWTs at 20 GHz, one on plus one spare, two 5-W TWTs at 30 GHz, one on plus one spare, transistor amplifier at 12.5 GHz



Olympus television broadcast payload.



Olympus satellite.

24-dBW ERP at 20 and 30 GHz, 10-dBW ERP at 12.5 GHz minimum over Europe

Receiver

TVB: in 17.6- to 18.1-GHz band

Two receivers with FET preamps, one on plus one spare

5.8 receiver noise figure

0 dB/K G/T

BSP: 13.175 or 14.100 GHz, and 13.200 or 14.125 GHz (18-MHz channels);

13.180 or 14.105 GHz and 13.220 or 14.145 GHz (30-MHz channels)

Four receivers, all active

+2.9 dB/K G/T at edge of coverage

COM: in 28- to 28.7-GHz band

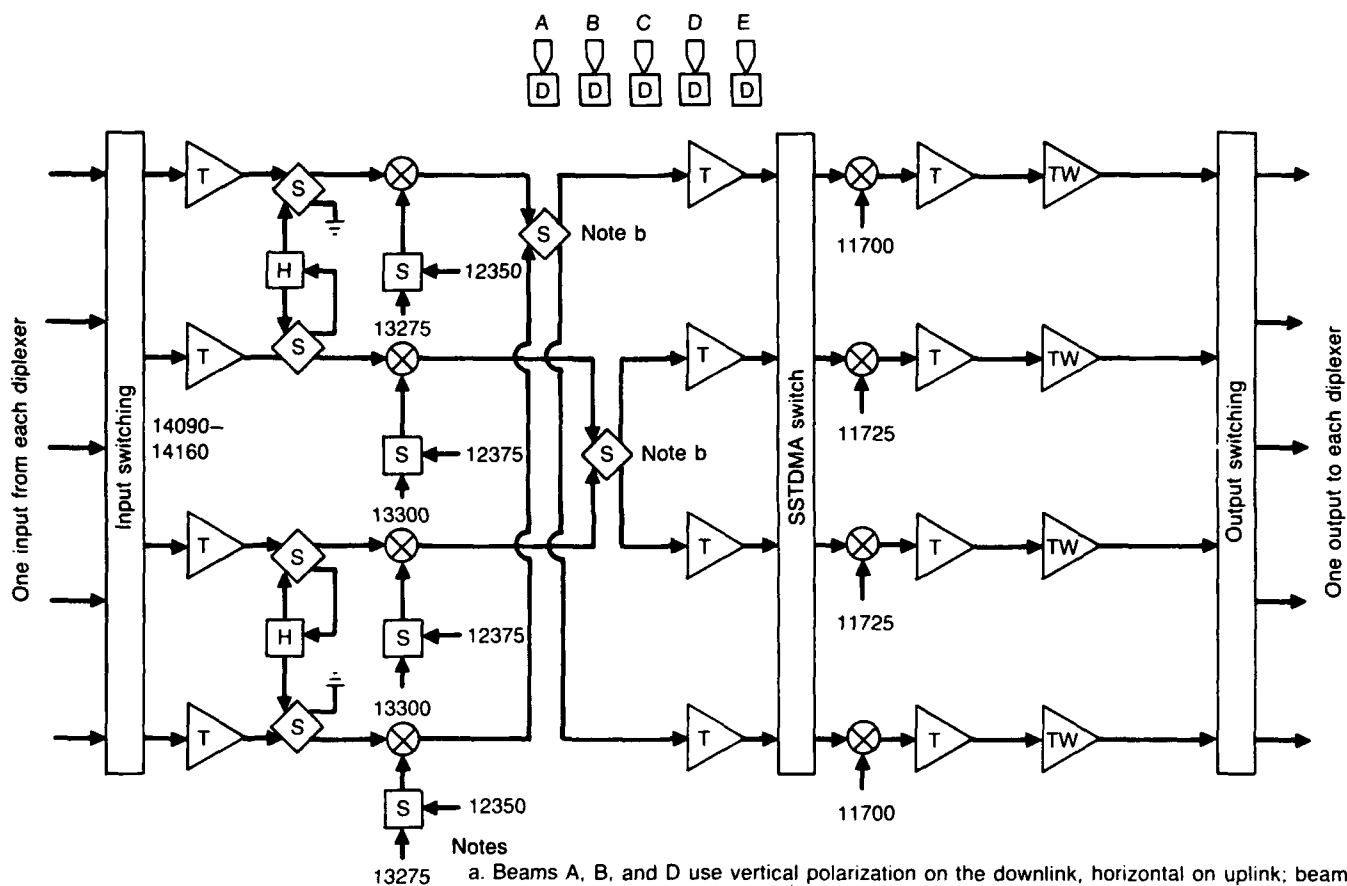
Two receivers with parametric amplifiers, one on plus one spare

4.5-dB receiver noise figure

+8 dB/K G/T at edge of coverage

Antenna

TVB: 40- × 80-in. reflector, 1- × 2.4-deg beam, steerable within Europe (beam 1); 47-in. reflector, 1.5-deg beam, steerable within



Olympus business services payload.

Europe (beam 2): 19-in. reflector, 2- × 3.3-deg beam for European coverage (receive); all use circular polarization

BSP: 47-in. reflector with five feed horns to form five adjacent beams, 1.2 deg (transmit), 1.1 deg (receive), linear polarization

COM: two 32-in. reflectors, each forming one beam, 1.2 deg (transmit), 1 deg (receive), each steerable within Europe, linear polarization

PROP: three horns, 17.5 deg (earth coverage) at 12.5 GHz, 9 deg (centered on Europe) at 20 and 30 GHz, linear polarization

Design life

Ten years

Orbit

Synchronous equatorial, 19°W longitude

Orbital history

Launched 12 July 1989, Ariane launch vehicle

Management

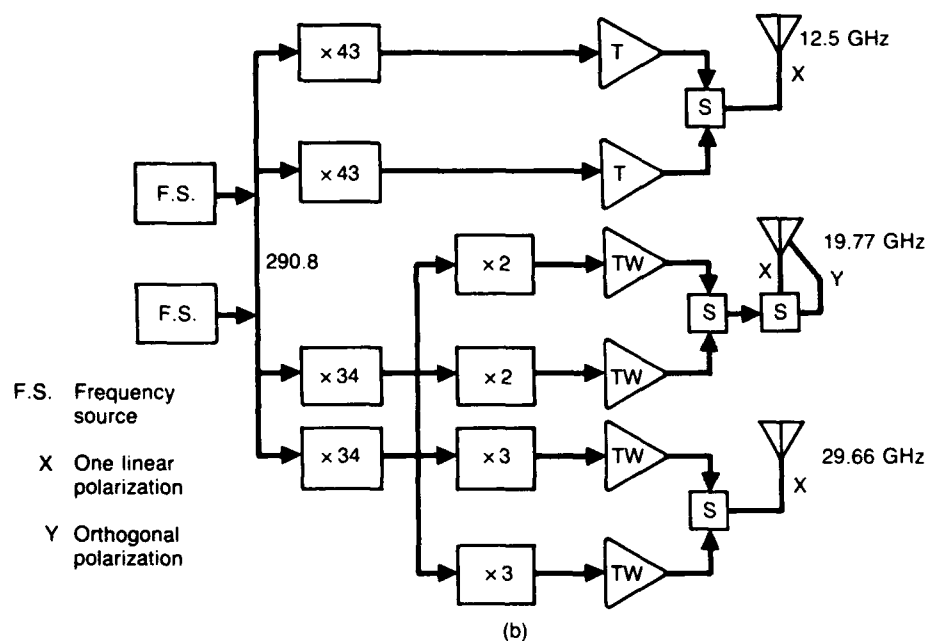
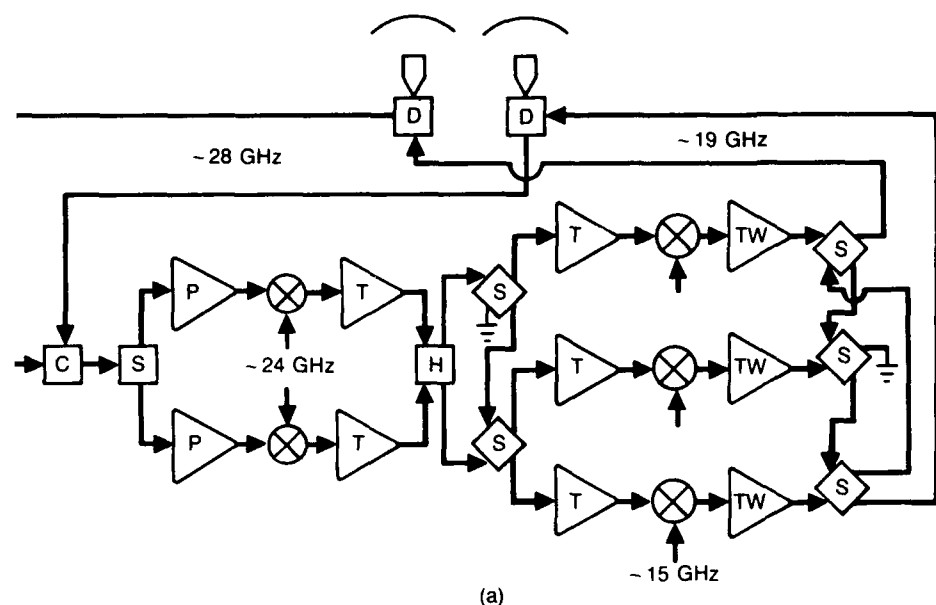
Developed for ESA by British Aerospace with subcontractors from 11 European countries and Canada; Selenia (Italy) has prime responsibility for the payloads

Olympus has four payloads. The television broadcast payload has two channels, each connected to a separate, steerable transmit antenna. One channel is used for preoperational direct-to-home

broadcasting in Italy. The other is used for direct-to-home broadcasting experiments and is available to European nations on a time-shared basis. It can also be used for broadcasting multilingual programs to all of Europe for reception by larger terminals. The second channel has a choice of two frequencies and two polarizations for flexibility in matching TV broadcast system characteristics specified for each nation at a 1977 ITU conference. The first channel has characteristics matching the specifications for Italy.

The payload has three antennas, one for reception and two for transmission. The Italian transmit antenna has circuitry for deriving antenna pointing information by tracking a ground-based beacon. The payload has redundant wideband receivers and redundant transmitters, with 230-W helix type TWTs, for each channel.

The business services payload, or specialized services payload, demonstrates concepts for transmission of digital data between small terminals (e.g., 10-ft antennas) at many sites. The downlink is at 12 GHz; the uplink may be either 13 or 14 GHz and is accommodated by switching the local oscillator in the satellite. A single antenna fed by five horns generates five adjacent beams, which together cover most of Europe. Frequency reuse will be demonstrated in two pairs of spatially separated beams. The communications equipment has four channels. Channel bandwidth is 18 MHz, or one or two channels may be switched to 30-MHz bandwidth. Input and output switches can form many



Olympus 20/30-GHz payload. (a) communications; (b) propagation.

one-to-one connections between these channels and the receive and transmit beams. In addition, in the central section of the channels, at an intermediate frequency of 825 MHz, there is a TDMA switch matrix that can change receiver-to-transmitter connections up to 256 times per 20 msec frame. This switch can connect a receiver to one or several transmitters. Payload demonstrations primarily use QPSK transmissions with a 25-Mbps TDMA rate in the 18-MHz channels, and either one television signal or four FDMA video conferences in the wider channels.

The 20/30-GHz communications payload has two antennas, each of which may be steered toward any point in Europe. The electronics support two channels. The two are transmitted through separate antennas; reception may use either or both antennas. The payload has redundant receivers and three transmitters. The payload is used for both data and video transmissions to

demonstrate satellite hardware and system operation in the 20/30-GHz frequency bands. These bands have more spectrum allocated to space communications than the 4/6-GHz and 12/14-GHz bands combined. Thus, they will gradually come into use over the next decade as the demand for satellite capacity continues to increase. A disadvantage is that the propagation impairments caused by rain increase with frequency.

Because of this problem, Olympus has a 20/30-GHz propagation payload. The output of an onboard frequency source is multiplied to produce frequencies at about 20 and 30 GHz. These are transmitted through antennas whose beams cover all of Europe for use in propagation measurements. The transmitted signals are not modulated. From the same frequency source, a 12.5-GHz beacon is derived. This is transmitted on an earth coverage beam and

is intended both for use in propagation measurements and as a tracking beacon for all Olympus ground terminals.

Olympus was launched in 1989. All four payloads are in use for over 100 different experiments. Experiments and demonstrations are being conducted by government organizations, universities, scientific organizations, private common carriers, and equipment manufacturers. The television broadcast payload, besides TV broadcasts to Italy, is being used for other TV broadcasts, sound broadcasts, educational TV, and interactive video services. The business services payload is being used for SS-TDMA tests, distribution of video to small (e.g., 3-ft antenna diameter) terminals, two-way low-rate data communications to very small terminals, electronic document delivery, and other services. The 20/30-GHz payload uses include business communications, broadcast of high-definition TV, data relay to and from low orbit satellites, video conferencing, education, and other projects with digital data and video transmissions. The propagation payload is being used at many places in Europe and two in North America.

In January 1991, one of the two solar arrays failed, but the satellite continued in service. In March, the one remaining earth sensor began having problems. This led to more complex satellite operations, which combined with the failure of the sensor and operator error and caused loss of all attitude and orbit control in May 1991. The satellite began spinning, internal temperatures dropped, and the batteries discharged. Work began immediately to regain control of the satellite, and progress was being made through the summer.

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EUTELSAT SYSTEM

Eutelsat [1-13] is an international organization formed to provide pan-European communications via satellite. Its genesis was 1977, when seventeen nations formed Interim Eutelsat to commercialize the OTS-ECS technology being developed by ESA. Definitive agreements were prepared in 1982 and ratified by member nations in the following years. Eutelsat had a formal beginning in 1985 with twenty-six members and grew to twenty-eight members by 1990. The largest shareholders are the United Kingdom and France at about 15% each; Italy and West Germany have about 10% each and other nations have 6% or less, down to less than 1% for principalities such as Liechtenstein and Monaco. Eutelsat provides services using several ECS, also called Eutelsat satellites, and formerly used one Telecom 1 satellite. A second-generation space segment, the Eutelsat II satellites, started development in 1986. The first was launched in 1990 and is in use.

Eutelsat's headquarters and communications control center are in Paris. The control center coordinates allocation of satellite resources and monitors all transmissions. It also coordinates system operations with the satellite control centers: ESA for the Eutelsat satellites, Telecom for the Telecom 1 satellite, and Eutelsat for the Eutelsat II satellites. The Eutelsat control stations are located in France and Portugal. The Eutelsat control network is capable of controlling six satellites.

When Interim Eutelsat started, it was intended to provide an extension of the terrestrial public communications network. The two primary services would be international public telephone circuits and television distribution for the EBU. By 1980, it was realized that there was also an emerging market for high-speed (i.e., 4-kbps and above) digital circuits for business use, a service that could not be provided by the existing terrestrial network. The decision to provide business services in a full way led to a decision to modify the ECS design. Two transponders operating in a frequency band well suited to business services were added to all the satellites except the first. Also, in the early 1980s, a demand for television distribution to cable networks arose. Eutelsat now provides these four types of service.

Public telephony is provided on four Eutelsat transponders. Transmissions are QPSK/TDMA with a burst rate of 120.832 kbps and a 2-msec frame. TDMA characteristics are almost identical to those of Intelsat and permit easy interconnection of the two networks. Digital speech interpolation is used. Ground terminals, usually only one per country, have antenna sizes of about 46 to 60 ft. Ten were in operation in mid-1986, fifteen a few years later. The same terminals, plus transponders on the same satellite, provide television distribution for the EBU.

Business services, also called satellite multiservices, began with one transponder on Eutelsat I-F2 and five, leased from France, on a Telecom 1 satellite. Eventually, all of these services were transferred to Eutelsat satellites. Typical applications are video conferencing, computer-to-computer links, fast facsimile, electronic mail, and voice. All links are digital; rates are multiples of 64 kbps up to 1.92 Mbps, plus 2.048 Mbps. Most ground terminals have 11- to 18-ft antennas; some, near the edge of the satellite beam, use diameters up to 26 ft. These terminals may be either dedicated to one customer's location or sited in an urban area to be shared by several customers. Most terminals are unmanned and monitored from a central facility.

On Eutelsat, the transmissions are QPSK/SCPC/TDMA. On Telecom 1, the transmissions were PSK/TDMA at a burst rate of 4.576 Mbps. TDMA transmissions in all five transponders were

synchronized. Each terminal transmitted to only one transponder but used frequency hopping to receive from as many as necessary. Error correction coding may be used with either satellite.

Eutelsat leases transponders which are being used for television transmission, both internationally and intranationally. Leases may be full time or part time, for a whole or partial transponder. The original Eutelsat plan was to have two satellites in orbit, a primary and a spare. Capacity on the spare satellites was to be leased on a preemptible basis. When Eutelsat requested bids for leases, the initial demand was three times the available capacity. Eutelsat allocated the available capacity on the F1 satellite and decided to expand to a three-, then a four-satellite system, with two satellites dedicated to leased transponders. Realization of this plan was delayed by the loss of ECS 3 but was achieved by 1988 with the launches of ECS 4 and 5.

Prior to the first ECS launch, Eutelsat was already planning for follow-on satellites. Eutelsat requested, and received, proposals for the Eutelsat II satellites in 1985 and picked a contractor team in April 1986. The contract was for three satellites with options for five more. A fourth satellite was ordered in 1987, a fifth in 1989, and a sixth in 1990.

Besides these satellites, Eutelsat has been considering satellites for two other missions. One is direct-to-home television broadcasting. Several individual nations are using satellites for this, but a pan-European broadcast also is possible. The satellite concept has been named Europesat. This concept has been studied for several years. By the end of 1990, an agreement had been reached to proceed with a program. Definition of the system is expected in 1991 with a satellite contract possible in 1992.

The other mission is land mobile communications for voice, message, and position location. This mission can be satisfied by separate satellites, by a new payload on Eutelsats, or by use of Eutelsats as is. The last option does not provide full mobile communications but is the easiest to implement. Demonstrations were conducted in 1990 of a two-way message and position location technique called Euteltraes, which is the same technique used in the United States under the name Omnitraes. A full Euteltraes system, using a Eutelsat I made available by transferring traffic to Eutelsat II satellites, will go into operation in 1991.

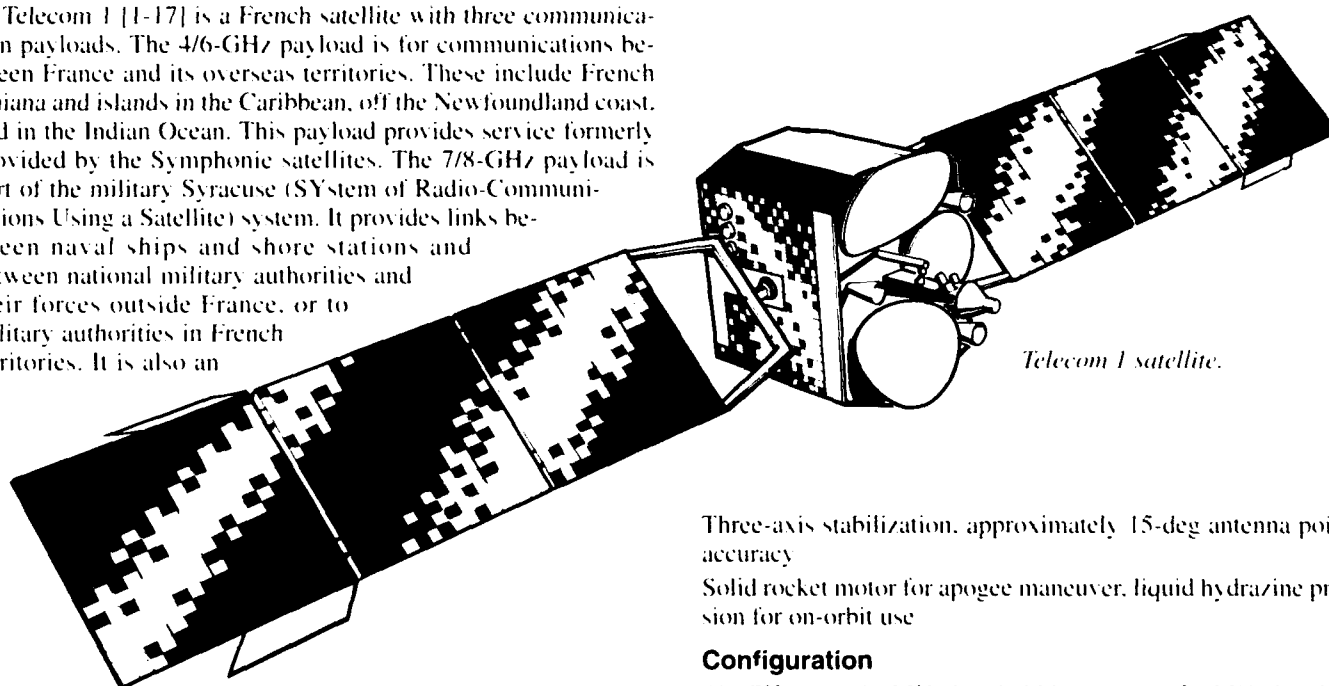
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TELECOM 1

Telecom 1 [1-17] is a French satellite with three communication payloads. The 4/6-GHz payload is for communications between France and its overseas territories. These include French Guiana and islands in the Caribbean, off the Newfoundland coast, and in the Indian Ocean. This payload provides service formerly provided by the Symphonie satellites. The 7/8-GHz payload is part of the military Syracuse (SYstem of Radio-Communications Using a Satellite) system. It provides links between naval ships and shore stations and between national military authorities and their forces outside France, or to military authorities in French territories. It is also an



Telecom 1 satellite.

alternative for military communications within France. The 12/14-GHz payload is for business communications and television transmission, the latter in France and the former in both France and other parts of Europe.

The satellite is a derivative of ECS and is similar in external appearance except for the antennas. Like ECS, the satellite has a service module and a payload module. The former includes the internal structure, three sides of the rectangular body, and the support subsystems including the solar arrays. These arrays have three sections each and are deployed in orbit. The payload module includes all the communications equipment mounted on the north, south, and earth-viewing faces of the body. The antennas, three parabolic reflectors and three horns, are all fixed to the earth-viewing face. The satellite and payload details are as follows:

Satellite

Rectangular body approximately 4.7 × 4.7 × 6.3 ft; deployed solar arrays span approximately 60 ft
1430 lb in orbit, beginning of life
Solar cells and NiC⁺ batteries, approximately 1100 W end of life

Three-axis stabilization, approximately 15-deg antenna pointing accuracy

Solid rocket motor for apogee maneuver, liquid hydrazine propulsion for on-orbit use

Configuration

4/6-GHz: two 40-MHz bandwidth and two 120-MHz bandwidth single-conversion repeaters

7/8-GHz: two 40-MHz bandwidth single-conversion repeaters

12/14-GHz: six 36-MHz bandwidth single-conversion repeaters

Capacity

4/6-GHz: approximately 1000 voice circuits or one TV transmission per 40-MHz repeater

12/14-GHz: 25 Mbps per repeater with small (approximately 10-ft antenna) ground terminals

Transmitter

4/6-GHz: 3700 to 3740 MHz, 3755 to 3875 MHz, 3890 to 3930 MHz, and 4075 to 4195 MHz

One 8.5-W TWT per repeater plus two spares

ERP 28 dBW over France, 26.5 dBW over coverage area (channels 1, 3, 4); 35 dBW over coverage (channel 2)

7/8-GHz: 7330 to 7370 MHz and 7255 to 7295 MHz

One 20-W TWT per repeater, plus one spare

ERP 27 dBW at edge of coverage

12/14-GHz: 12,504 to 12,750 MHz

One 20-W TWT per repeater plus one spare for every two repeaters

ERP 47 dBW over France; ground terminals in neighboring countries may use the satellite by accepting up to 3 dB lower performance.

Receiver

4/6-GHz: 5925 to 5965 MHz, 5980 to 6100 MHz, 6115 to 6155 MHz, and 6300 to 6420 MHz

One active plus one spare receiver

G/T -12 dB/K

7/8-GHz: 7980 to 8020 MHz and 8055 to 8095 MHz

12/14-GHz: 14,004 to 14,250 MHz

One active plus one spare receiver with parametric amplifiers

G/T +6.3 dB/K over France; ground terminals in neighboring countries may use the satellite by accepting up to 3 dB lower performance

Antenna

4/6-GHz: earth coverage horn, 16.7-dB gain at edge of coverage (receive); one helix illuminates one of the 12-GHz reflectors to provide a spot beam over Guiana and French Caribbean islands, approximately 28-dB gain (channel 2 transmit); five helices illuminate a 31-in. dia. reflector to provide semiglobal coverage (channels 1, 3, 4 transmit)

7/8-GHz: two earth coverage horns, one transmit, one receive, approximately 19-dB gain at edge of earth, circular polarization

12/14-GHz: two offset-fed parabolic reflectors, each 31 × 50 in., 1.34 × 2.04-deg beam, one for odd channel transmit, the other for even channel transmit and all reception; linear polarization

Design life

Seven years

Orbit

Synchronous equatorial, stationkeeping to ±0.05°N-S and E-W

Orbital history

1A: launched 4 August 1984, in use, 9°W longitude

1B: launched 8 May 1985, failed in 1988, moved above synchronous orbit

1C: launched 11 March 1988, in use, 5°W longitude
Ariane launch vehicle

Management

Developed by MESH Consortium, Matra (France) is prime contractor, for Direction Generale des Telecommunications (French National Telecommunications Agency)

Operated by Direction Generale des Telecommunications

The 4/6-GHz payload has four channels. All are received through an earth coverage antenna and one of two redundant receivers. Each channel has a separate transmitter path. One channel is connected to a feed horn which forms a spot beam using one of the 12-GHz reflectors. The beam covers Guiana and the French Caribbean Islands. The other three channels are connected to a semiglobal coverage beam that includes France and all the territories previously mentioned. This payload is used for television and TDM/QPSK/FDMA telephony and data, at rates from 64 kbps to 52 Mbps.

The 7/8-GHz payload has two channels. It has separate, global coverage horn antennas for reception and transmission, redundant

receivers, and three TWTs, one for each channel and one spare. All transmissions are digital, at 75 bps, 2400 bps, or 16 kbps, and use spread spectrum modulation for both multiple access (CDMA) and resistance to jamming. This payload is used by ship terminals, two types of transportable terminals, and fixed terminals. Their respective antenna diameters are 5, 4, 10, and 26 ft.

The 12/14-GHz payload has six channels. The equipment configuration is the same as the other payloads—redundant wideband receivers followed by channelized transmitters with three for two TWT redundancy. This payload has two antennas, both of which form elliptical beams whose -3 dB contours are about the size of France. Communications with other countries is possible within the -6 dB contour, which extends from northern Italy to England. One channel from this payload is used for distribution of television programs. The other five channels are used for business communications between small ground terminals (antenna diameter about 10 ft for terminals within the -3 dB satellite antenna contour). Individual links have information rates between 2.4 kbps and 2.048 Mbps. System operation uses demand assignment and TDMA with a transmission rate of 24.576 Mbps. Part of the capacity on these five channels is used within France; the remainder was used as part of the Eutelsat system. This payload also is used by some groups in Germany, Britain, and other European countries.

The different missions of the three payloads motivated the choice of the separate frequency bands. The 4/6-GHz band was selected to minimize attenuation because of the high rainfall in some of the overseas territories. The 7/8-GHz band is allocated to systems that use a mix of fixed, transportable, and mobile terminals. It also offers the possibility of interoperability with the NATO satellite system. The 12/14-GHz bands are dedicated to satellite communications and thus permit small terminals to be optimally located for the business services with no interference problems. Because of the three frequency bands, considerable attention was given to frequency planning and techniques to minimize active and passive onboard interference. The 4-GHz transmission frequencies were selected to avoid second harmonics in the 8-GHz receiver. The 7-GHz transmission frequencies were selected so that all harmonics were above the 14-GHz receiver passband. Also, frequencies that could be produced by combinations of outputs from different transmitters were analyzed.

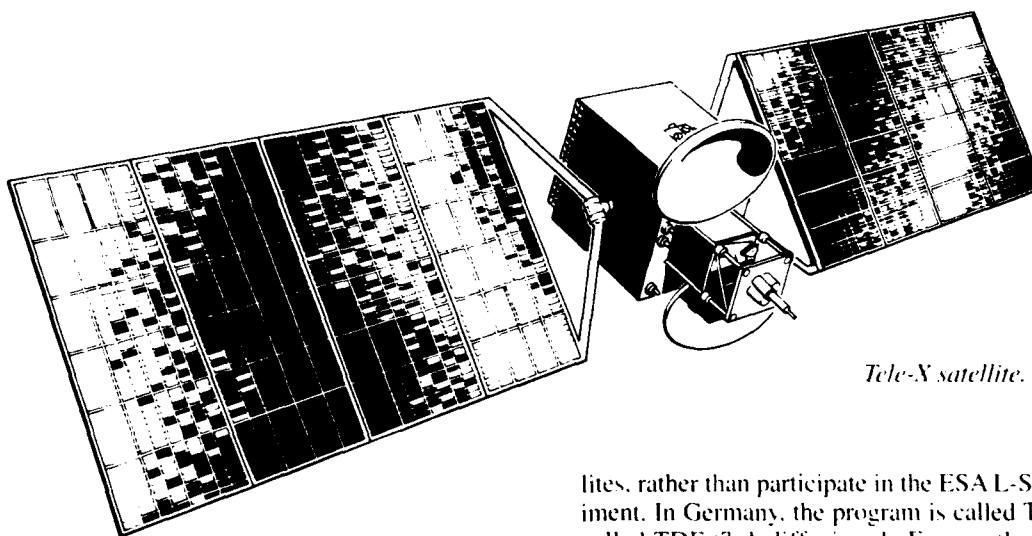
The decision to develop Telecom 1 was made by the French Government in 1979. Telecom 1A was launched in August 1984, and Telecom 1B was launched in May 1985. At the end of 1987 and beginning of 1988, Telecom 1B had power problems which disabled first one, then both, sides of the attitude control subsystem. By February 1988, the satellite was useless. The next month, Telecom 1C was launched and restored services. Telecom 1A will reach the end of its design life in 1991 and shortly after will be replaced by the first Telecom 2 satellite.

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TV-SAT, TDF, AND TELE-X



Tele-X satellite.

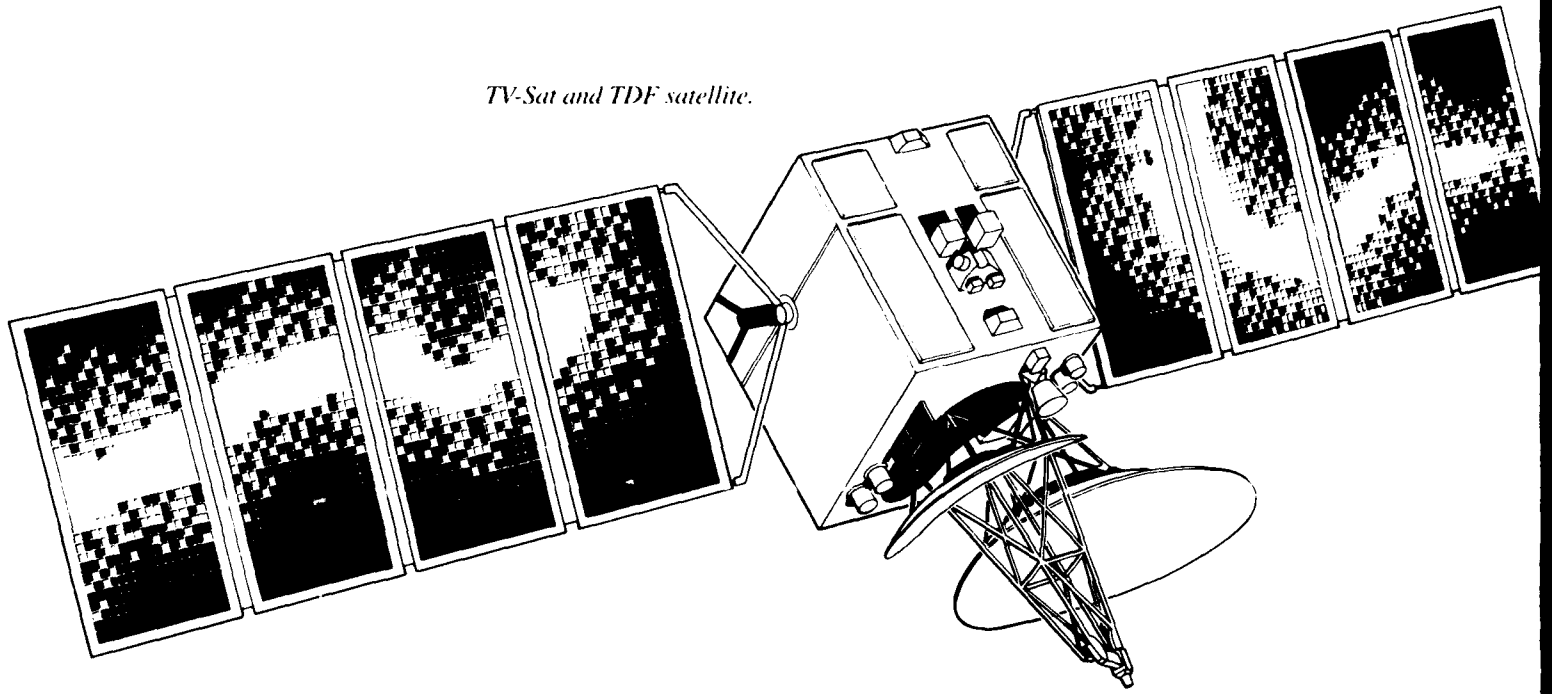
German studies of satellite broadcasting of television directly to home receivers started in 1971. Relevant technology developments were started in 1972. In 1977, the ITU Space Broadcasting conference assigned basic parameters for satellite broadcasting satellites for all European, African, and Asian countries. The parameters include satellite location and transmission frequency, polarization, beam shape, and power. These assignments assure every country of the ability to deploy a satellite broadcasting system and limit intersystem interference to an acceptable level.

Subsequent to the 1977 conference, several European nations started planning initial, or preoperational, systems. Both single-nation and multinational systems were considered. In late 1979, Germany and France agreed to jointly develop broadcasting satel-

lites, rather than participate in the ESA L-Sat broadcasting experiment. In Germany, the program is called TV-Sat; in France, it is called TDF (Telediffusion de France, the name of the national broadcasting company). The program began in 1981, and included development work and assembly of three satellites, one for each country and one spare. Later, it was expanded to four satellites, two for each country.

During the late 1970s, the five Scandinavian countries discussed a joint development program called Nordsat. Because of technical and economic reasons, the program was postponed. In 1980-81, a Swedish experimental communications satellite program was defined. The satellite was called Tele-X; it was to have four payloads, of which one was for television broadcasting. In the next year, two payloads were deleted to reduce the cost. In 1983, a contract was signed with the TV-Sat/TDF industrial team to develop Tele-X as a variant of those satellites. In the same year, Norway and Finland became partners in the program.

TV-Sat and TDF satellite.



The satellites [1-30] are identical except for details of the broadcasting payload such as frequency and antenna beam pattern. Also, Tele-X has fewer broadcast channels but an added payload for data transmission. The satellites are composed of several modules. A liquid bipropellant propulsion subsystem is used for the apogee maneuver, stationkeeping, and attitude control. The service module includes the attitude control electronics, telemetry and command, and power regulation functions. Satellite attitude control is augmented by an uplink beacon, tracked by the communication subsystem, which provides fine pointing control for the transmit antenna. The solar arrays are another module. They are composed of rigid rectangular frames supporting flexible blankets on which solar cells are mounted. One section of each array is deployed in transfer orbit; the remainder when the operational orbit is reached. The communications module includes all payload electronics and the heat pipes and thermal radiators for the payload. The antenna module includes the feed tower and the two large reflectors, which are folded against the tower for launch. Satellite and payload details are as follows:

Satellite

Rectangular body, 65 × 88 × 95 in.; span of solar arrays 62 ft; height, including antenna feed tower, 17 to 23 ft

Approximately 2620 lb in orbit, beginning of life

Solar cells and NiCd batteries, 3090 W (TV-Sat, TDF)/3300 W (Tele-X) minimum after seven years

Three-axis stabilization using momentum wheels, ±0.06- to ±0.1-deg antenna pointing accuracy using RF sensing of an uplink beacon

Unified bipropellant propulsion for apogee maneuver and on-orbit use

Configuration

TV-Sat, TDF: five 27-MHz bandwidth single-conversion repeaters, four active simultaneously

Tele-X: three 27-MHz bandwidth single-conversion repeaters (TV broadcast); one 40-MHz and one 86-MHz bandwidth repeaters (data transmission)

Capacity

One TV signal per 27-MHz repeater

Transmitter

TV-Sat: 11.7467, 11.8234, 11.9001, 11.9768, and 12.0535 GHz (ITU satellite broadcasting channels 2, 6, 10, 14, 18)

TDF: 11.7275, 11.8042, 11.8809, 11.9576, and 12.0344 GHz (ITU satellite broadcasting channels 1, 5, 9, 13, 17)

Tele-X: 12.2069, 12.3220, and 12.4755 GHz (ITU satellite broadcasting channels 26, 32, 40) 12.641 and 12.723 GHz (data and video transmission)

TV-Sat: one 230-W TWT per repeater operated at 200 to 210 W; one repeater has a spare TWT

TDF: one 260-W TWT per repeater; one repeater has a spare TWT

Tele-X: one 230-W TWT per repeater (TV broadcast); one 230-W TWT per repeater, operated at 60 to 150 W; plus one spare TWT (data transmission)

ERP at edge of coverage: ≥65.5 dBW (TV-Sat), 63.8 dBW (TDF), >60 dBW (Tele-X, TV broadcast), ≥59 dBW (Tele-X, data transmission)

Receiver

TDF: 17.3 to 17.7 GHz, G/T 12.5 dB/K on axis

TV-Sat: 17.7 to 18.1 GHz, G/T approximately 12 dB/K on axis

Tele-X TV broadcast: in 17.7- to 18.1-GHz band, >7 dB/K G/T on axis

Tele-X data and video transmission: 14.141- and 14.223-GHz, 8 dB/K G/T over coverage area

One active plus one spare receiver per frequency band

Antenna

TV-Sat: one 55- × 106-in. parabolic reflector offset fed by a single horn generating a 0.72- × 1.62-deg LHCP transmit beam, approximately 45-dB gain; one 78-in. offset-fed parabolic reflector generating a 0.7-deg RHCP receive beam

TDF: one 35- × 94-in. parabolic reflector offset fed by a nine-horn array generating a 0.98- × 2.5-deg RHCP transmit beam, approximately 41 dB gain; one 78-in. offset-fed parabolic reflector generating a 0.7-deg LHCP receive beam

Tele-X: one 45- × 96-in. parabolic reflector, offset fed by a single horn in a Cassegrain geometry generating a 0.74- × 1.64-deg LHCP transmit beam; one 31- × 67-in. parabolic reflector, offset fed by a single horn in a Cassegrain geometry generating a 0.95- × 2.10-deg receive beam

All transmit antennas have cross-polarization power 33 dB below operating polarization

Design life

Nine years (changed from initial value of seven years)

Orbit

Synchronous equatorial, stationkeeping to $\pm 0.1^\circ$ N-S and E-W, 19° W longitude (TV-Sat, TDF), 5° E longitude (Tele-X)

Orbital history

TV-Sat 1: launch 27 November 1987, failed during initial deployment, moved above synchronous orbit

TDF 1: launched 28 October 1988, in use, 19° W longitude

Tele-X: launched 2 April 1989, in use, 5° E longitude

TV-Sat 2: launched 8 August 1989, in use, 19° W longitude

TDF 2: launched 24 July 1990, in use, 19° W longitude

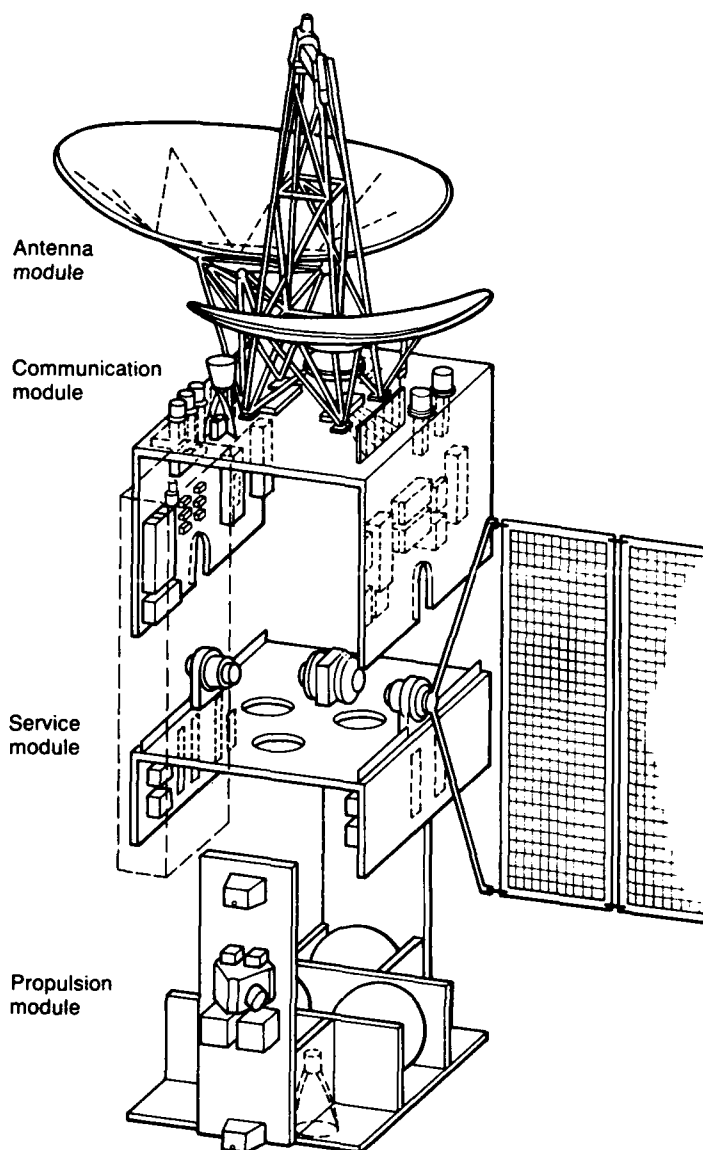
Ariane launch vehicle

Management

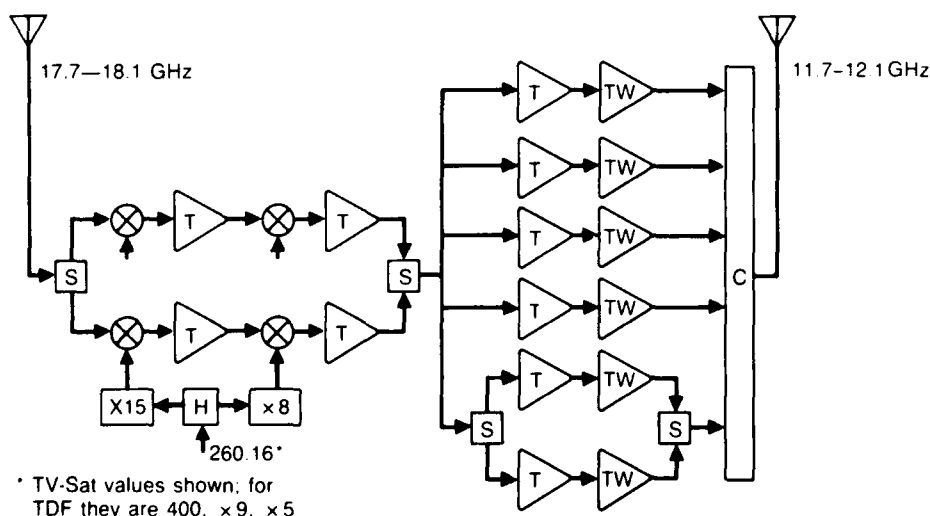
Developed by Eurosatellite Consortium, MBB prime contractor for TV-Sat, Aerospatiale prime contractor for TDF and Tele-X

TV-Sat developed for Deutsche Forschungs- und Versuchsanstalt für Luft- und Raumfahrt and Deutsche Bundespost, TDF developed for Telediffusion de France and Centre National d'Etudes Spatiales, Tele-X developed for Swedish Space Corporation acting for Swedish Board of Space Activities

TV-Sat operated by Deutsche Forschungs- und Versuchsanstalt für Luft- und Raumfahrt and Deutsche Bundespost; TDF by Telediffusion de France; Tele-X by Swedish Space Corporation

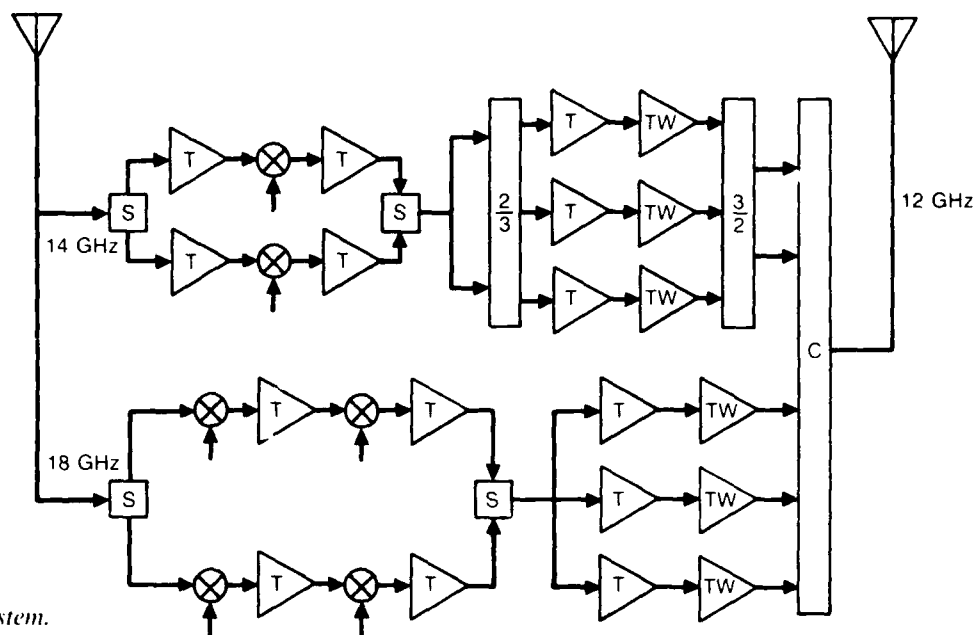


TV-Sat and TDF satellite details.



* TV-Sat values shown; for TDF they are 400, $\times 9$, $\times 5$

TV-Sat and TDF communication subsystem.



Tele-X communication subsystem.

The 1977 conference allocated five channels each to Germany and France. The TV-Sat/TDF communication subsystem includes all five channels. The original design was to operate only three at a time, but the actual satellite capability as built allows operation of four at a time and of all five during the early part of the satellite's life. All five channels are accommodated by the wideband receivers. Each channel has a separate driver amplifier and TWT. The driver amplifier incorporates automatic level control to compensate for atmospheric attenuation variations on the uplink. The saturated output power of each TWT is 230 to 260 W. The collectors of the TWTs radiate directly to space and operate at a temperature above 300°C.

The Tele-X communication subsystem includes both the broadcasting and data channels. There are three broadcasting channels, shown in the lower half of the figure, which use the same hardware as TV-Sat and TDF. The two data channels have a 14-GHz receiver; their transmitter uses the same hardware as the broadcasting channel. One channel has a 40-MHz bandwidth, the other an 86-MHz bandwidth. The data channel TWTs are operated 2 to 6 dB below saturation for better linearity, since multiple carriers will be amplified. As with TV-Sat and TDF, four of the five Tele-X channels may be operated simultaneously. Both broadcasting and data channels use the same antennas; the antenna pattern covers Sweden, Norway, and Finland.

Satellite integration and testing for TV-Sat and TDF started in the first half of 1985. TV-Sat was launched first in 1987. One of the solar arrays could not be deployed in orbit, neither by the intended means nor by several other means that were tried. This not only reduced the available power but more importantly blocked the receiving antenna deployment, so that it could not be pointed at the earth. Several tests were conducted with the satellite, but it could not be used for broadcasting. Hence, it was declared a loss in the spring of 1988.

TDF was launched in 1988. Construction of TV-Sat 2 and TDF 2 began in 1986 and 1985, respectively, and they were launched in 1989 and 1990. Each of the TDF satellites has had two TWTAs fail. The remaining channels are being used for television broadcasting. TV-Sat 2 is operating and is used for television and high-quality stereo sound broadcasting.

Both nations studied follow-ons to these satellites. The continual improvements in technology for home receivers now allow lower power satellite transmitters. This allows more channels possible per satellite or a broader coverage. Either prospect improves the economics of a satellite broadcasting system. By 1990, France had decided to pursue the broader coverage approach via a European rather than a national system. No specific program or launch date has been established.

Tele-X was ordered by the Swedish Space Corporation, but prior to launch another company, Nordiska Telesatelit (Notelsat), was established to be the nominal owner and actual operator. Through the latter half of the 1980s, the nordic countries' investment in the Tele-X program fluctuated, and government policies were not favorable to the use of the satellite (the prime goal in its development was increasing the technological abilities of Swedish industry). When the satellite was launched in 1989, there were both broadcasting and data transmission users for it, but regulatory issues remained. By 1990, two television broadcasters were using the satellite. Other companies with about fifty ground terminals, with 5- to 8-ft antennas, use the satellite for business transmissions, especially videoconferencing. Transmissions are QPSK/FDMA with 2 Mbps the most common rate.

No plans for a post-Tele-X satellite have been announced.

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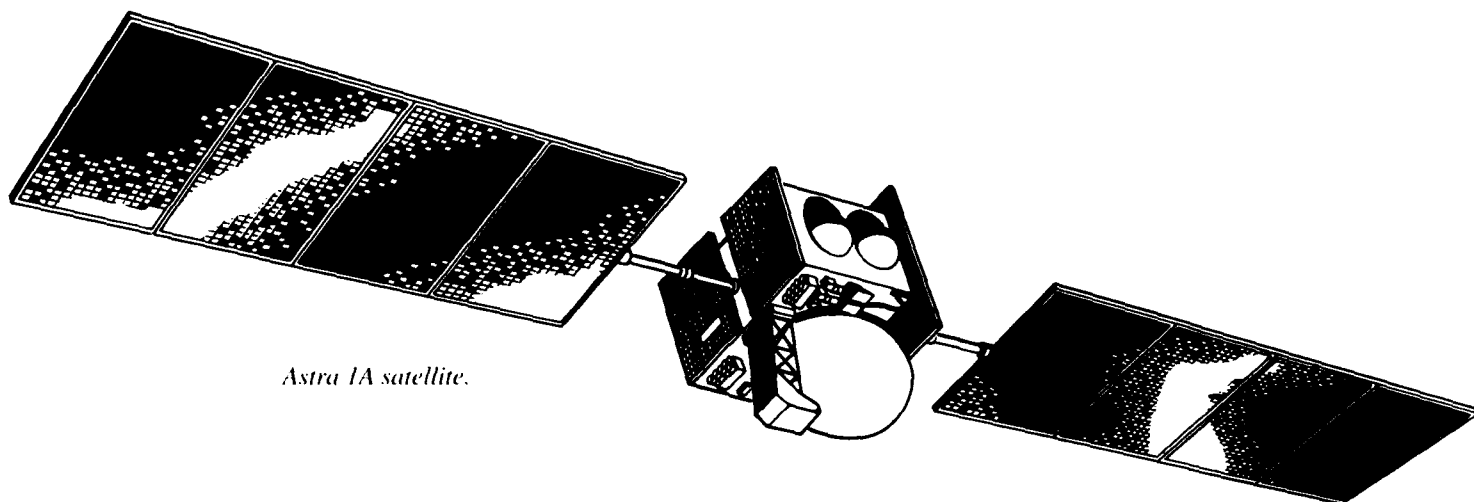
ASTRA

Communication satellites were studied in Luxembourg since the early 1980s. The country is obviously too small to require its own satellite. Rather, the ideas are aimed at European coverage, which has drawn opposition from Eutelsat. Eutelsat is supported by the national communications agencies of the European nations which strongly regulated communications until the end of the 1980s, and in a few nations still do. Thus, with opposition from Eutelsat, the prospects for a Luxembourg-based system were poor.

In 1984, a project named Coronet became the primary satellite activity in Luxembourg. The plan was to use a satellite with many medium-power transponders to provide acceptable television broadcasting to home receivers at a cost per channel much lower than the high-power satellites in development (e.g., TDF, TV-Sat). In 1985, Coronet placed an order for a sixteen-transponder satellite. That same year, Coronet was replaced by Société Euro-

péenne des Satellites (SES), which assumed the satellite contract. SES is a private company in Luxembourg with some indirect investment by, and direct support from, the government. The support was very important, because SES faced a difficult series of negotiations to have their system accepted by telecommunications regulators in other European countries. The acceptance was achieved, and the system [1-4] went into operation early in 1989, a few months after the first satellite was launched.

The SES satellites are named Astra. Astra 1A was ordered in 1985 and launched in 1988. Astra 1B was ordered in 1989 and launched in 1991. The satellites are not identical, but both are very similar to satellites used for United States domestic communications. Both have typical three-axis-stabilized designs: a box-shaped body with solar arrays that deploy in orbit. The antenna on Astra 1A is fixed on the earth-viewing face, whereas the Astra 1B antenna deploys in orbit.



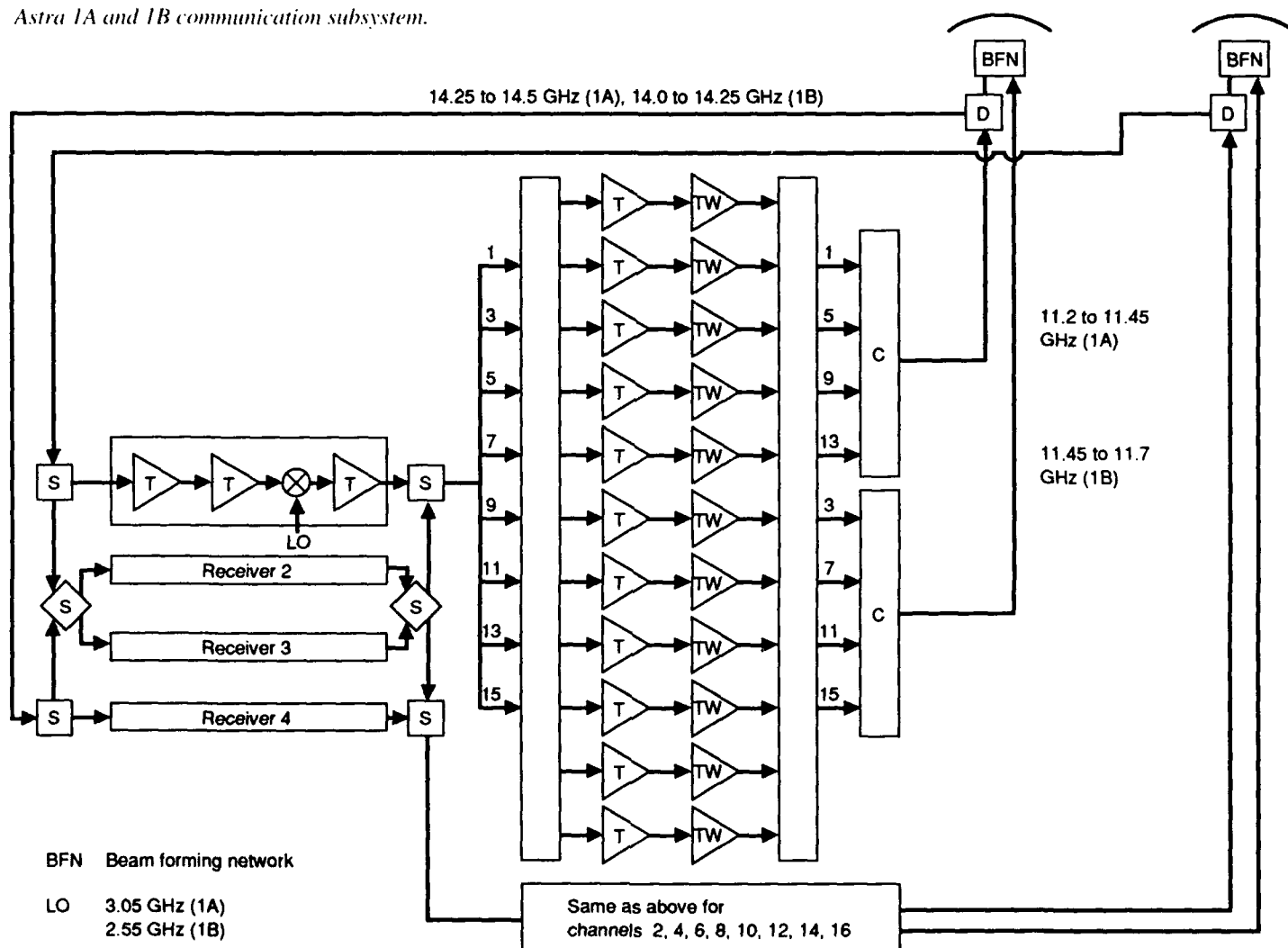
Astra 1A satellite.

Astra 1B is the larger satellite. When SES contracted for it, it was almost completely built as Satcom K3 for United States domestic use. Thus, it was ready for launch in only a year and a half. The main rework was to modify the antenna pattern for European coverage. Since it was larger, it had the power and thermal capacity to accommodate higher power transmitters than Astra 1A. It

also has a larger, longer focal length antenna which led to better beam shaping for the coverage desired by SES.

Astra 1A and 1B each have sixteen transponders. Their frequencies are adjacent rather than identical, so that they can be collocated in orbit. This allows ground receivers to get up to thirty-two signals with one antenna pointed at their common location. Other aspects of these satellites are:

Astra 1A and 1B communication subsystem.



Satellite

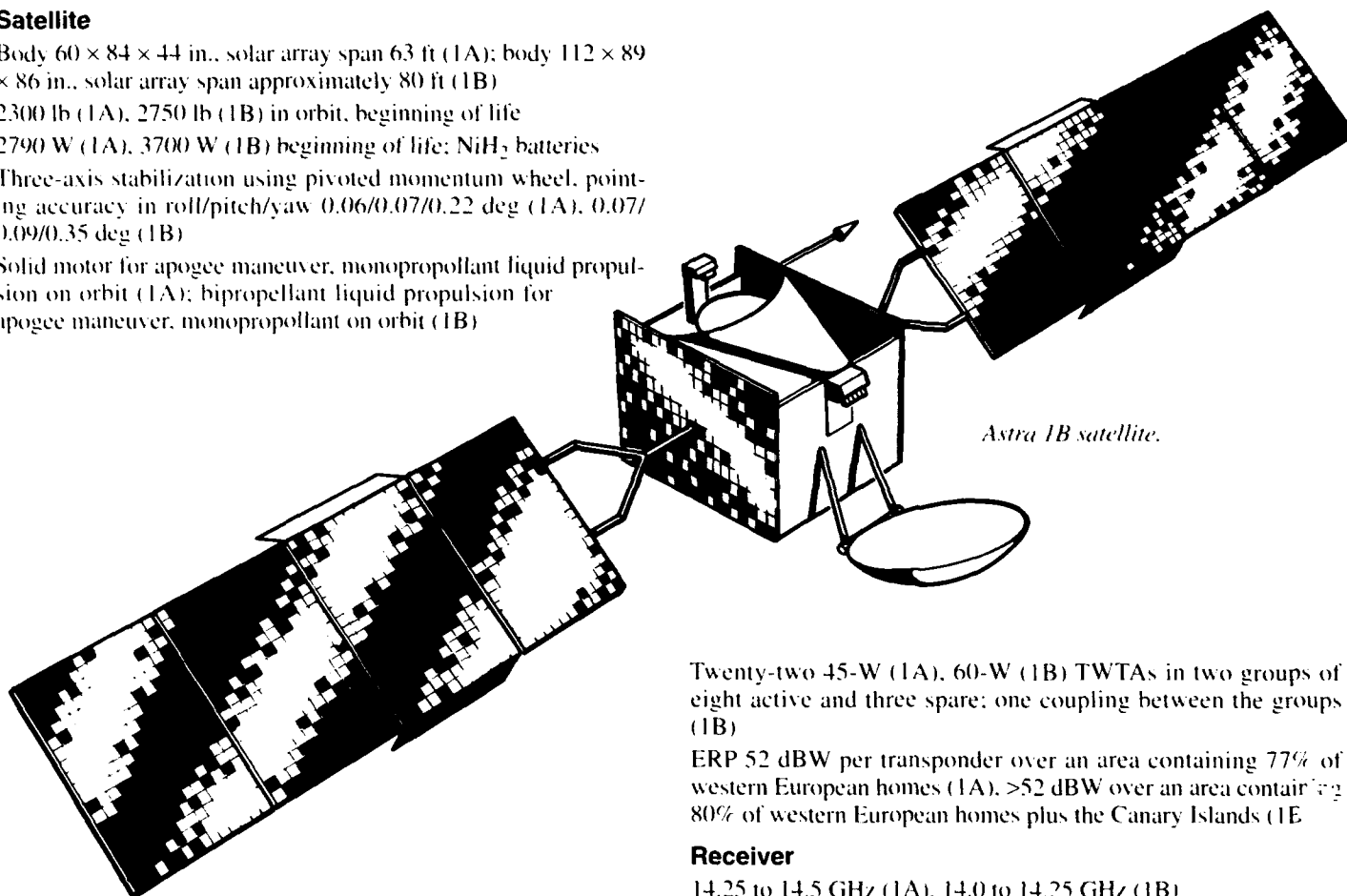
Body $60 \times 84 \times 44$ in., solar array span 63 ft (1A); body $112 \times 89 \times 86$ in., solar array span approximately 80 ft (1B)

2300 lb (1A), 2750 lb (1B) in orbit, beginning of life

2790 W (1A), 3700 W (1B) beginning of life; NiH_2 batteries

Three-axis stabilization using pivoted momentum wheel, pointing accuracy in roll/pitch/yaw 0.06/0.07/0.22 deg (1A), 0.07/0.09/0.35 deg (1B)

Solid motor for apogee maneuver, monopropellant liquid propulsion on orbit (1A); bipropellant liquid propulsion for apogee maneuver, monopropellant on orbit (1B)



Astra 1B satellite.

Configuration

Sixteen 26-MHz bandwidth, single-conversion transponders, dual-polarization frequency reuse (1A, 1B)

Transmitter

11.2 to 11.45 GHz (1A), 11.45 to 11.7 GHz (1B)

Twenty-two 45-W (1A), 60-W (1B) TWTAs in two groups of eight active and three spare; one coupling between the groups (1B)

ERP 52 dBW per transponder over an area containing 77% of western European homes (1A), >52 dBW over an area containing 80% of western European homes plus the Canary Islands (1B)

Receiver

14.25 to 14.5 GHz (1A), 14.0 to 14.25 GHz (1B)

Two active, two spare receivers

G/T +4 dB/K (1A), +6 dB/K (1B)

Antenna

One dual-gridded offset-fed parabolic reflector, dia. 60 in. (1A), 84 in. (1B); one feed array per polarization, eight horns per array (1A), twelve and thirteen horn arrays (1B); 34-dB transmit and receive gain (1A), 38-dB transmit and 36-dB receive gain (1B); cross-polarization isolation >30 dB

Design life

Ten years

Orbit

Synchronous equatorial, stationkeeping to $\pm 0.05^\circ$ N-S and E-W

Orbital history

1A: launched 10 December 1988, in use, 20° E longitude

1B: launched 2 March 1991

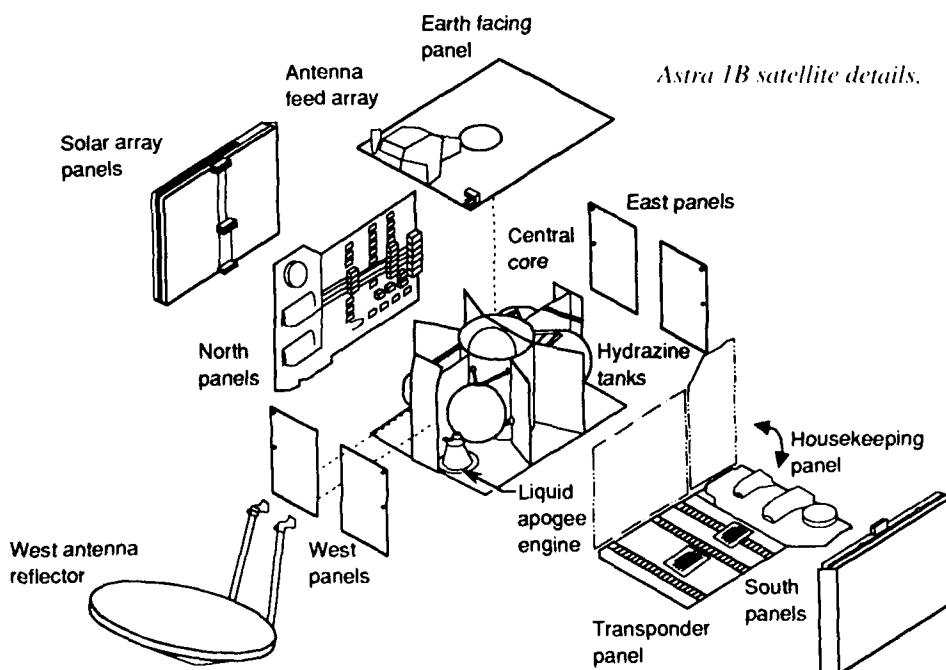
Ariane launch vehicle

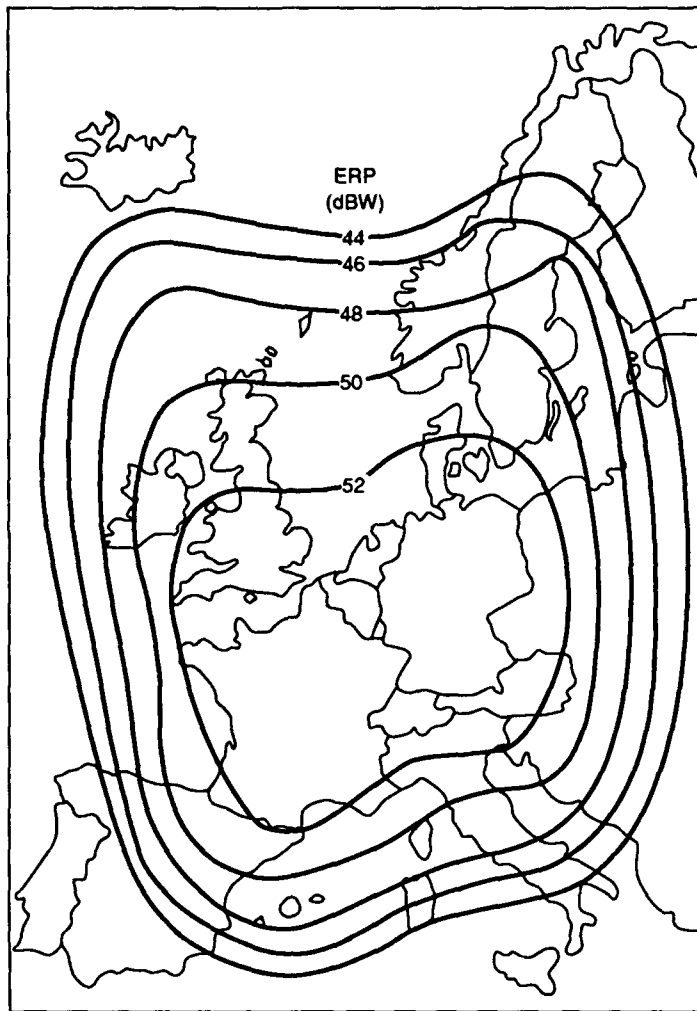
Management

Developed for SES by GE Astro Space (formerly RCA Astro Electronics)

Operated by SES

Astra 1B satellite details.





Astra 1A coverage area.

The Coronet plan to focus on television broadcasting turned out to be a good one, even though the satellites are not limited to that. Television's use of satellites in Europe grew much faster than the business communications that other systems had expect-

ed to be their main user. Television broadcasting to homes has not grown as fast as expected by SES, but many cable TV operators receive and redistribute the SES signals.

The primary service area for Astra 1A includes England, France, Germany, Denmark, the Low Countries, Switzerland, Austria, and northern Italy. Ground antenna sizes as small as 2 ft are able to provide acceptable signal quality for home viewing. Cable system operators use larger antennas for better signal quality. By doubling the ground antenna size, the coverage expands to all the British Isles, and half of Norway, Sweden, Italy, and Spain. Astra 1B has slightly larger coverage than 1A, plus an additional, switchable coverage for the Canary Islands.

When Astra 1A began operations, the broadcasters using it were concentrated in England and Scandinavia. Use of the satellite increased slowly through 1989; but by the end of 1990 it was fully utilized, and all available transponders on Astra 1B were leased. The increased use includes an increase in the nationalities of the broadcasters. The success of SES, which was not generally predicted through 1988, became obvious in 1990.

In 1990, SES requested proposals for one or two more satellites. In December, it announced an order for Astra 1C and 1D. They will be similar to the earlier satellites although built by a different manufacturer. Their launches are planned for 1993 and 1994.

* * * * *

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4. *Satellite Communications* (October 1983), p. 10; (January 1984), p. 10; (October 1987), p. 45; (March 1988), p. 23; (May 1988), p. 42; (September 1988), p. 25; (September 1989), p. 16; (June 1990), p. 29.

KOPERNIKUS

West Germany was a relatively small country with a well-developed terrestrial communications network. Communication satellites have been added to this network to improve distribution of television programs, to improve communications with West Berlin, and to provide for the recent interest in digital communications for business applications. The use of satellites started in 1984 with one leased Eutelsat transponder. In 1985, West Germany started using several leased Intelsat transponders for both television and data transmissions.

Development of the DFS (Deutsche Fernmeldesatellit, German Telecommunications Satellite) system [1-8] started in 1983. It includes the Kopernikus satellite, thirty-four earth terminals, and other terrestrial equipment. The satellite is composed of three modules: satellite bus, communications, and antenna. The technology used in the satellite is based on the ECS and TV-Sat developments. The bus module contains the various support subsystems and provides the primary structure for the satellite.

The two solar arrays deploy when the satellite is in synchronous orbit; each array has three panels. A bipropellant propulsion subsystem is used for the apogee maneuver and all subsequent requirements.

The communications equipment is mounted on the two parallel faces of the communications modules for close coupling to the thermal radiators. There are two sections of the communication subsystem that use the 11-12/14-GHz and 20/30-GHz frequency bands. Lower frequencies are used for the section intended for operational use. It has seven 44-MHz bandwidth transponders at 12/14 GHz and three 90-MHz bandwidth transponders at 11/14 GHz. Because of the split transmission band, frequency conversion is accomplished in the channelized transmitter rather than (as is common on most communication satellites) in the broadband receiver. The 20/30-GHz section of the communication subsystem has only one transponder and is intended for experimental use. Both sections use antennas of the same design, with beams

covering West Germany and Berlin. The same beams now provide good coverage of the united Germany. The antennas are fixed on the earth-viewing face of the satellite. Performance values are as follows:

Satellite

Body approximately $5 \times 5 \times 6$ ft, solar arrays span about 50 ft

Approximately 1800 lb in orbit

Sun-tracking solar arrays and NiCd batteries, 1500 W after ten years

Three-axis-stabilized using momentum wheels, ± 0.16 -deg accuracy

Unified bipropellant propulsion for apogee maneuver and for on-orbit use

Configuration

A: seven 44-MHz bandwidth single-conversion repeaters, 12/14 GHz, dual-polarization frequency reuse

B: three 90-MHz bandwidth single-conversion repeaters 11/14 GHz, dual-polarization frequency reuse

C: one 90-MHz bandwidth dual-conversion repeater, 20/30 GHz

Capacity

A: 60 Mbps or one TV signal per repeater

B, C: 140 Mbps or two TV signals per repeater

Transmitter

A: 12.5 to 12.75 GHz

One 20-W TWT per repeater plus three spares

49-dBW ERP per repeater at edge of coverage

B: 11.45 to 11.7 GHz

One 20-W TWT per repeater plus two spares

49-dBW ERP at edge of coverage

C: 19.78-GHz

One 20-W TWT plus one spare

48-dBW ERP at edge of coverage

Receiver

A: 14.0 to 14.25 GHz

B: 14.25 to 14.5 GHz

A and B share two active and two spare receivers

FET preamplifiers, 3.7 dB noise figure

8.9 dB/K G/T at edge of coverage

C: 29.58 GHz

Parametric amplifiers, 3.5-dB noise figure

One active, one spare receiver

7.7 dB/K G/T at edge of coverage

Antenna

A, B: one offset-fed Gregorian antenna, 53-in.-dia. reflector, 1.2-deg beamwidth, 39.3-dB gain at edge of coverage, dual linear polarizations, 32-dB cross-polarizations isolation

C: one offset-fed Gregorian antenna, 28-in. reflector, 1.2-deg beamwidth, 39-dB gain at edge of coverage

Design life

Ten years

Orbit

Synchronous equatorial, stationkeeping $\pm 0.07^\circ$ N-S and E-W

Orbital history

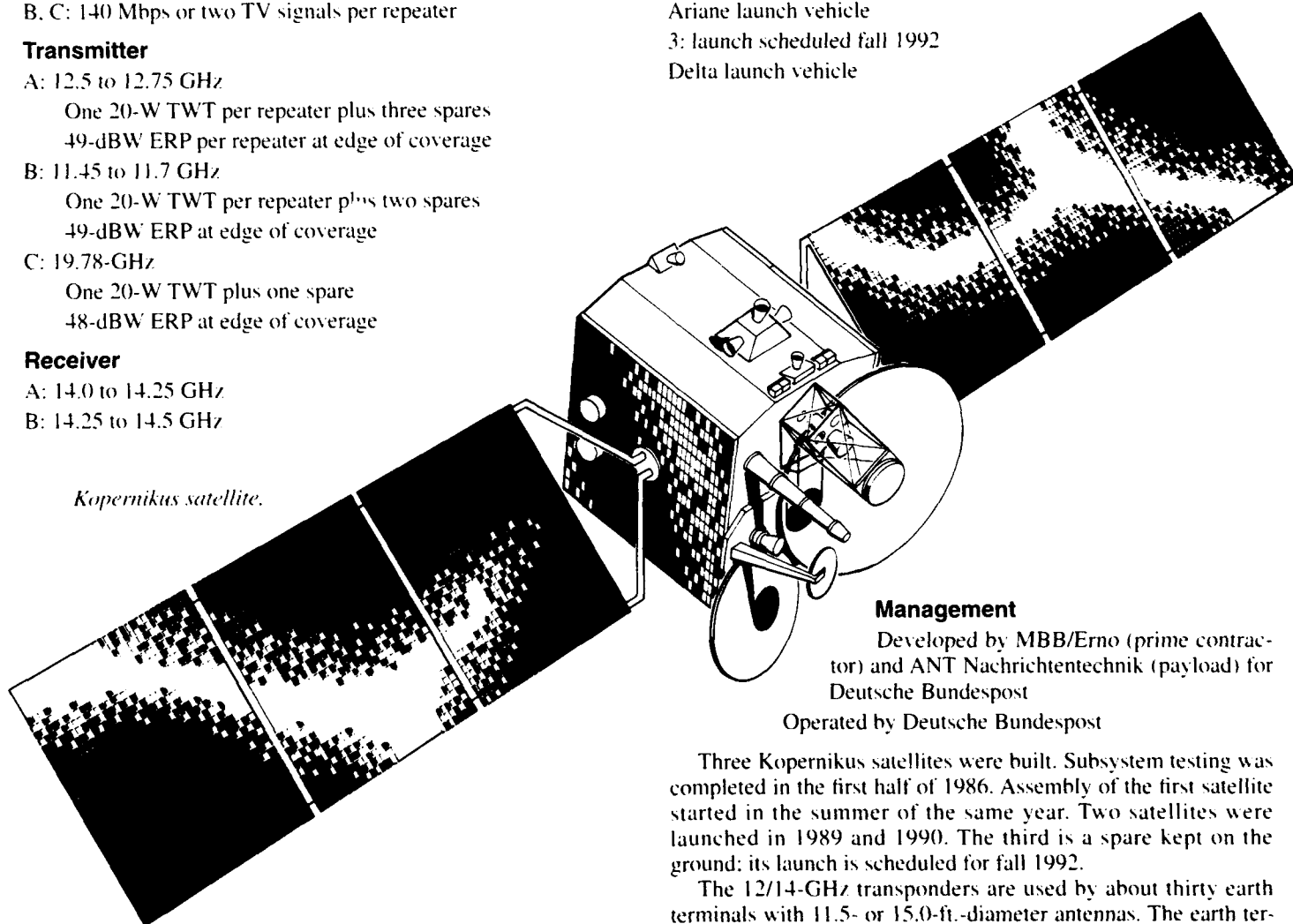
1: launched 5 June 1989, in use, 24° E longitude

2: launched 24 July 1990, in use, 29° E longitude

Ariane launch vehicle

3: launch scheduled fall 1992

Delta launch vehicle



Kopernikus satellite.

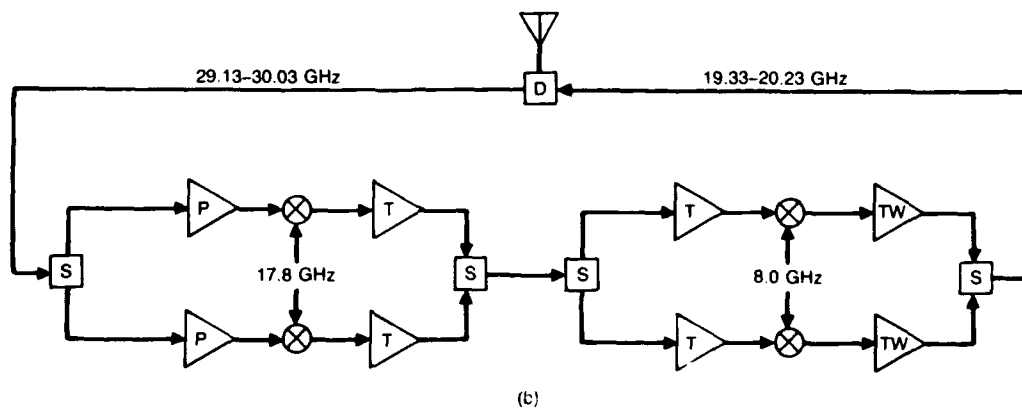
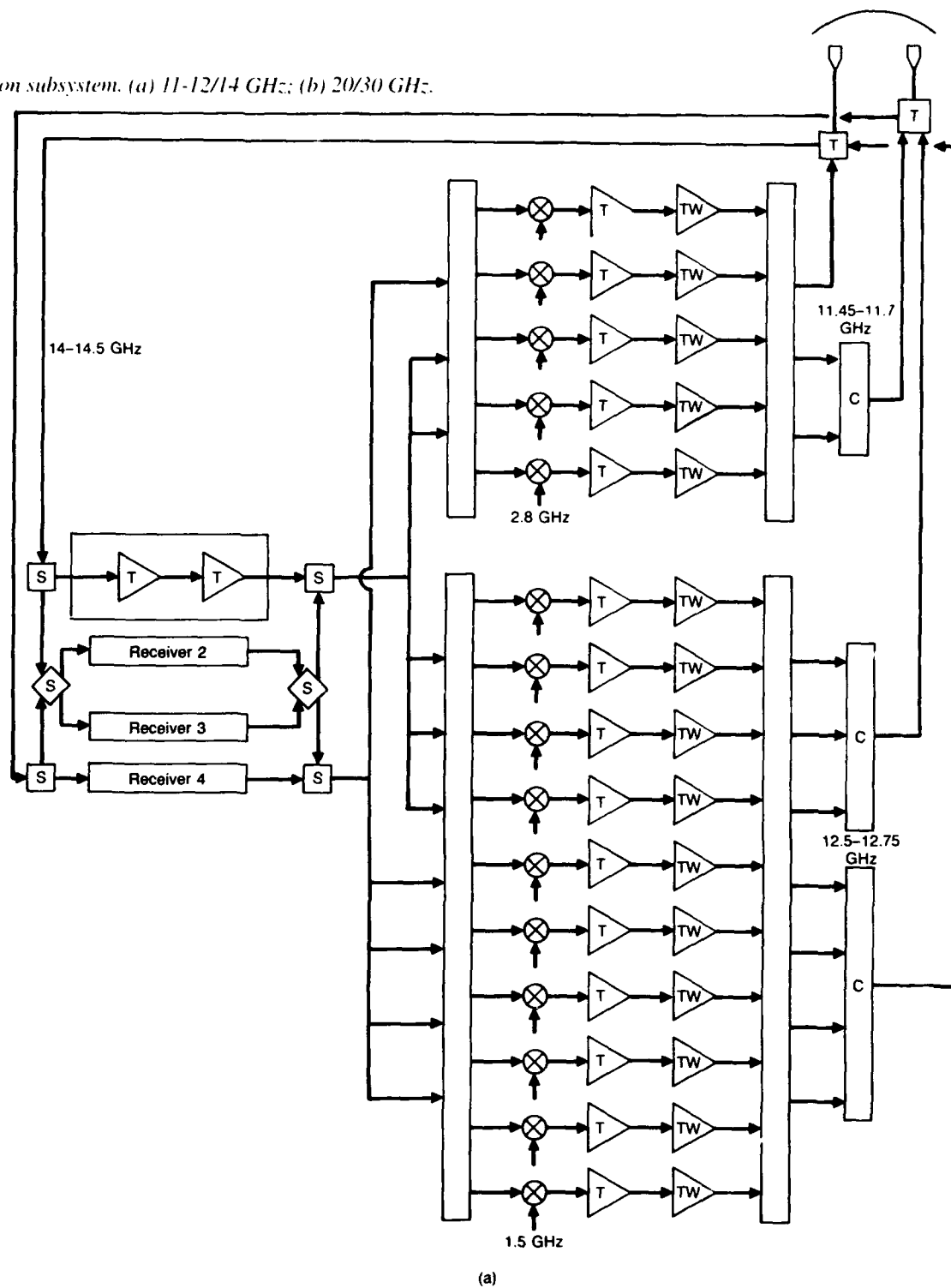
Management

Developed by MBB/Erno (prime contractor) and ANT Nachrichtentechnik (payload) for Deutsche Bundespost

Operated by Deutsche Bundespost

Three Kopernikus satellites were built. Subsystem testing was completed in the first half of 1986. Assembly of the first satellite started in the summer of the same year. Two satellites were launched in 1989 and 1990. The third is a spare kept on the ground; its launch is scheduled for fall 1992.

The 12/14-GHz transponders are used by about thirty earth terminals with 11.5- or 15.0-ft.-diameter antennas. The earth terminal population is expected to increase to 100. Some transponders are used for nationwide distribution of regional television



programs. The other transponders are for business communications such as computer network, facsimile, video conferencing, and electronic mail. Multiple users are connected to each terminal. The terminals will communicate in a TDMA network with intertransponder frequency hopping on reception. Base capacity is preassigned, but the peak capacity requirements of each terminal will be demand assigned. Transmission is QPSK at 60 Mbps; user information rates are 64 kbps to 2.048 Mbps.

The 11/14-GHz transponders are used for telephone trunk circuits and network television. Transponder capacity is two television signals or one 140 Mbps or two 40 Mbps QPSK signals. Initially, only two earth terminals were built, one of them in Berlin and one in Frankfurt. Both have 59-ft antennas. Two 20/30-GHz earth terminals, with 36-ft antennas, are being built in the same locations and will use the 20/30-GHz transponder for the same type of traffic.

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BRITISH SATELLITE BROADCASTING

The United Kingdom, in 1982, was the first European country to authorize a commercial satellite broadcasting project. "Commercial" is in contrast to the government-run TV-Sat and TDF programs in Germany and France. The United Kingdom project, called Unisat, was stopped in 1984 because costs had grown too much. In 1985, the Independent Broadcasting Authority, which regulates all British radio and TV broadcasting except the BBC, studied new approaches to organizing a satellite broadcasting project. A favorable decision was made, and a request for franchise proposals was advertised in 1986. This franchise was awarded to British Satellite Broadcasting, Ltd. [1-4] at the end of the year and covers a 15-yr period.

A satellite contractor was chosen in the spring of 1987. The contract was unusual in that it required delivery in orbit of a properly working satellite. The satellite contractor was required to make all arrangements for launch, and the satellite and launch contractors shared the risk for all failures, limited only by any insurance they could arrange.

The satellite is the first for television broadcasting to be designed with a spinning body and despun communications equipment platform. All others are designed with three-axis-stabilized bodies with large solar panels. The BSB satellite has five transponders corresponding to the five channel frequencies allocated to the United Kingdom by the ITU. Six power amplifiers are available for these five channels. Each amplifier is a pair of well-matched TWTs tied to a common power supply. Each amplifier may be used at high power (both TWTs on) or low power (one TWT on). The low-power mode is available even if one TWT fails. The satellite can provide enough power to support six TWTs simultaneously, which will usually be for three transponders in high-power mode. With two satellites in orbit for redundancy, three transponders on one and two on the other will fill the five allocated frequencies.

The satellite is launched as a compact cylinder. In orbit, a cylindrical solar array drum is deployed along its axis, thereby exposing a second solar array on the cylindrical surface of the

satellite body. This doubles the available power-generating capability while maintaining a compact launch configuration and has been used on many other satellites. The main antenna also is deployed in orbit, rotating about the hinge where it is attached to the satellite, and also unfolding along one higher line internal to the antenna. Additional satellite details are as follows:

Satellite

Cylindrical body, 7-ft 1-in. dia., 8-ft 10-in. tall stowed, 23-ft 7-in. tall deployed

1450 lb in orbit, beginning of life

Spinning solar array on satellite body and deployed drum, NiCd batteries, 1100 W beginning of life, 915 W end of life

Spin-stabilized, gyrostabilized with nutation damping, 0.05-deg antenna pointing accuracy

Solid motor for apogee maneuver, monopropellant hydrazine for on-orbit use

Configuration

Five 27-MHz bandwidth single-conversion transponders, three may be operated simultaneously at high power, or two at high power and two at half power, or one at high power and four at half power

Transmitter

11.785, 11.862, 11.938, 12.015, and 12.092 MHz (ITU broadcasting satellite channels 4, 8, 12, 16, 20)

Six TWTAs, each composed of two 55-W TWTs tied to a common power supply, 55-W or 110-W output, maximum of six 55-W TWTs on simultaneously

ERP 59 dBW over all of the United Kingdom, 61 dBW over 90%

Receiver

17.3 to 17.7 GHz

One active and one spare receiver

G/T 14 dB/K

Antenna

One 68- × 100-in. parabolic reflector, offset-fed by multiple feed horns to form a transmit beam approximately 0.75 × 1.8 deg. offset-fed by one feed horn to form a receiver beam. circular polarization

Design life

Ten years

Orbit

Synchronous equatorial, stationkeeping to ±0.1 N-S and E-W

Orbital history

1: launched 27 August 1989, operational, 31°W longitude

2: launched 18 August 1990, dormant and drifting near synchronous altitude

Delta launch vehicle

Management

Developed for British Satellite Broadcasting by Hughes Aircraft Company

Operated by British Satellite Broadcasting

The first satellite was launched in 1989 and placed at 31°W longitude in the synchronous orbit, which is the ITU-assigned location for broadcasting to the United Kingdom. This satellite sometimes has been named Marcopolo I. It was delivered to BSB there, in good condition, as specified in the contract. A satellite control station and an uplink broadcasting station, for transmitting signals to the satellite, have been built in southern England.

BSB started operations in spring 1990, first to cable systems and then to individual home receivers. It was required to allow reception by cable operators, but every home that connects to cable is one less that will buy an individual receiver and pay a yearly fee to BSB. Furthermore, a competitor, Sky Television, had been broadcasting television to the United Kingdom and Ireland since 1989, using Luxembourg's lower-power Astra satellite.

The competition from cable systems and Sky Television caused a bleak financial outlook for BSB. Through part of 1990, BSB and Sky Television publicly debated the merits of their broadcasts. Both were losing money, and in November 1990 they agreed to merge with the name British Sky Broadcasting. Since more homes had antennas for receiving from Astra than for receiving from the BSB satellite, broadcasting is now on Astra. This decision leaves BSB satellites largely or wholly unused. As a result, the second satellite has been left dormant in a drifting orbit, rather than being stabilized and activated at 31°W longitude. The future of the two satellites is uncertain.

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EUTELSAT II

Since the ECS/Eutelsat I satellites were designed by ESA, Eutelsat II [1-9] is the first series designed by and specifically for Eutelsat. The Eutelsat I operations uncovered a large market for business communications and even more for television distribution. Response to this market shaped the requirements for Eutelsat II. The primary differences between the two series of satellites are broader coverage and much higher power, improved redundancy, and more efficiency and flexibility in spectrum use on Eutelsat II.

The Eutelsat II satellite has sixteen transponders. All are received through a European coverage antenna beam. All can be transmitted through beams with the same coverage or switched in groups to a narrower beam which covers the core of Western Europe. The broader beam encompasses an area bounded by the Azore and Canary Islands in the Atlantic, the Mediterranean coasts of Africa and the Middle East, Turkey, the western limits of the Soviet Union, Finland, and Iceland. The narrower beam encompasses the area bounded by Spain, Italy, southern Scandinavia, and Great Britain. Six of the transponders can be individually switched between two different transmission frequencies as another aspect of the Eutelsat flexibility. This is shown in the frequency plan diagram, which also shows the transponder groupings for switching between the two antenna beams for transmission. The groups labeled a and b are transmitted through the west antenna, and group c through the east antenna, which also is the receive antenna for all transponders.

The European coverage beam is used for transmission of telephony, data, business services, and television distribution. The

narrow coverage beam is used for television transmissions to antennas with 2- and 3-ft diameters. Each beam uses both linear polarizations, with separate feed horns for each. The feed horns are attached to the satellite body, but the reflectors are stowed against the body and are deployed in orbit.

The satellite structure is similar to many others, having a box-shaped body composed of two modules, one for the payload and one for the supporting subsystems. There is space on the earth-viewing face of the body for antennas to work with additional payloads. Additional Eutelsat details are listed below:

Satellite

Body 9 × 6.5 × 8 ft, span across solar arrays 73.5 ft

Approximately 2000 lb in orbit, beginning of life

Sun-tracking solar arrays and NiH₂ batteries, 3000 W end of life

Three-axis stabilization using momentum wheels

Unified bipropellant propulsion for both apogee maneuver and on-orbit use

Configuration

Nine 36-MHz bandwidth, single-conversion transponders and seven 72-MHz bandwidth single-conversion transponders, dual-polarization frequency reuse

Transmitter

10.95 to 11.2 GHz, 11.45 to 11.7 GHz, 12.5 to 12.75 GHz

50-W TWTAs arranged in two rings of twelve, with eight active in each ring

ERP 39 to 44 dBW for European coverage, 47 to 52 dBW for narrow coverage

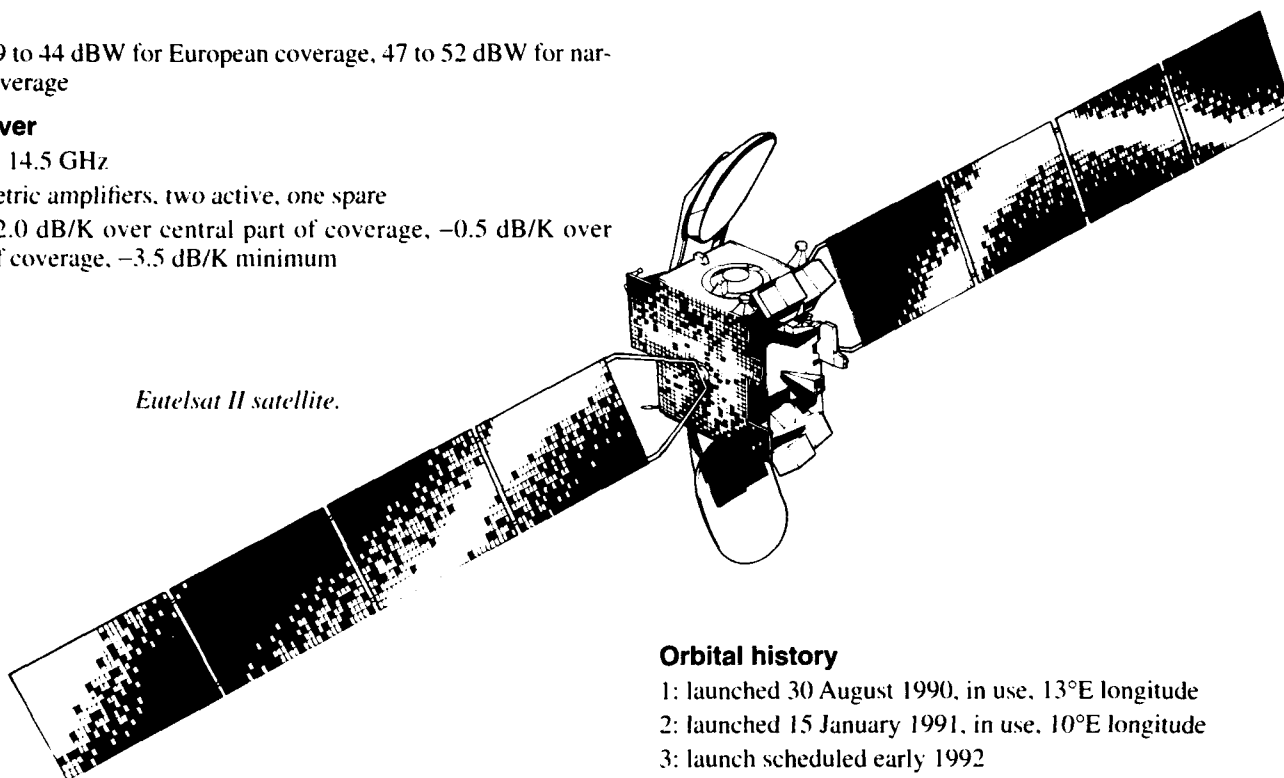
Receiver

14.0 to 14.5 GHz

Parametric amplifiers, two active, one spare

G/T +2.0 dB/K over central part of coverage, -0.5 dB/K over 90% of coverage, -3.5 dB/K minimum

Eutelsat II satellite.



Antenna

Two offset-fed, dual-gridded parabolic reflectors, each about 64 × 88 in. physically with an effective aperture of 64 in.; two feed arrays per reflector, one array per polarization, twenty or twenty-one horns per array, one antenna for transmission and reception, one for transmission only; dual linear polarizations

Design life

Seven years

Orbit

Synchronous equatorial, 6 to 19°E and 32 to 36°E longitude, stationkeeping to ±0.1°N-S and E-W

Orbital history

1: launched 30 August 1990, in use, 13°E longitude

2: launched 15 January 1991, in use, 10°E longitude

3: launch scheduled early 1992

4: launch scheduled February 1992

5: launch scheduled October 1992

6: available for launch in 1993

Ariane launch vehicle (1-2, 4-5), Atlas II launch vehicle (3)

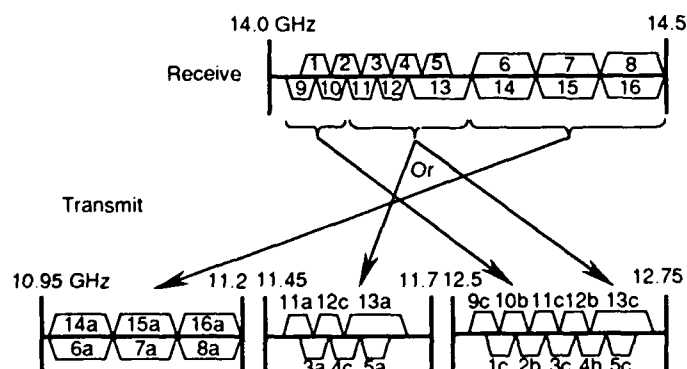
Management

Developed for Eutelsat by Aerospatiale (France) as prime contractor, with subcontractors in seven European nations

Operated by Eutelsat

The first Eutelsat II was launched in 1990 and the second five months later. During the early months of 1991, they are being integrated onto the Eutelsat system and taking over some of the traffic from Eutelsat I satellites. In addition, many Eutelsat II transponders have been leased for applications which could not be accommodated on Eutelsat I. Three more satellites will be launched in 1993. The contract still has options for seventh and eighth satellites.

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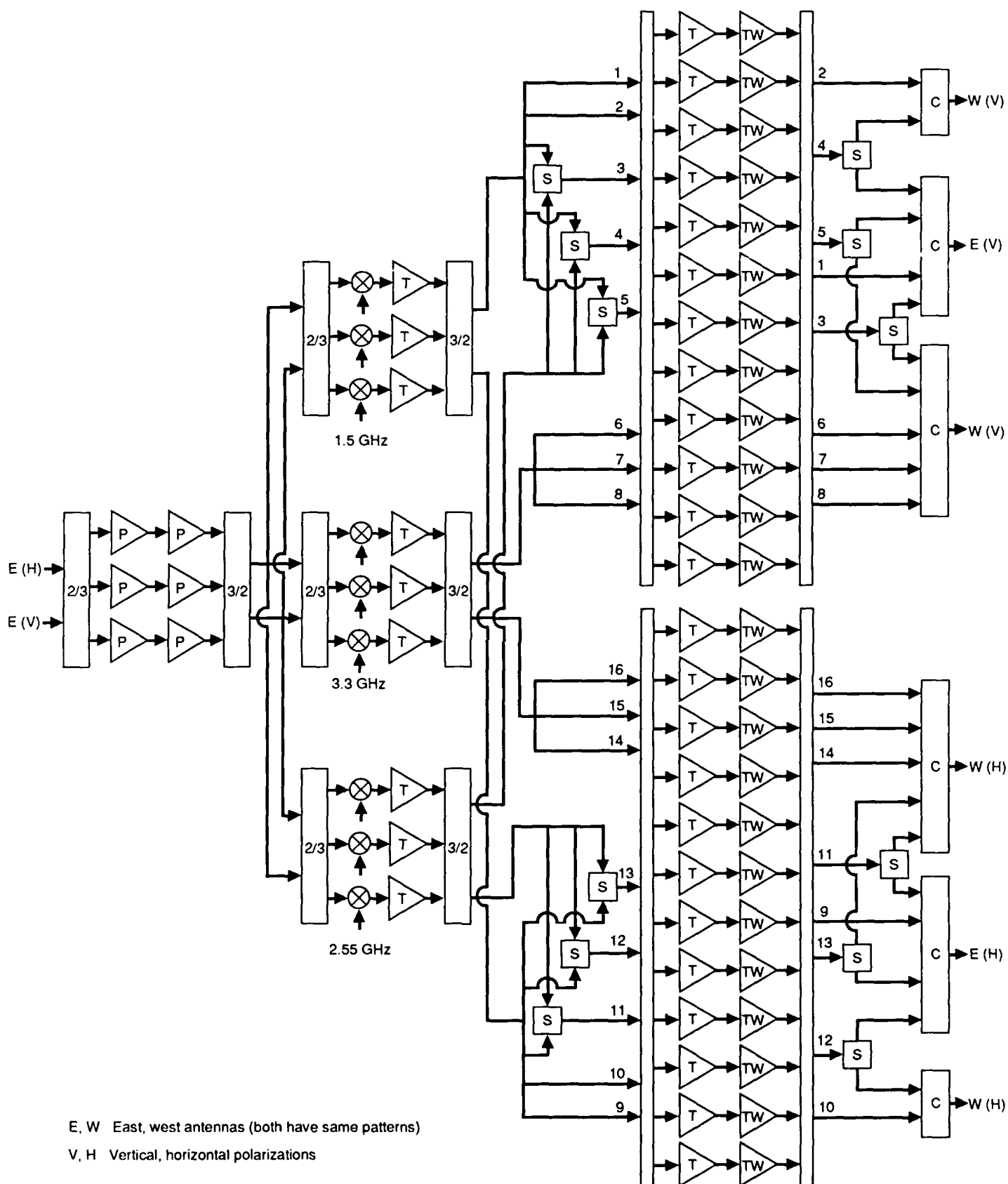
Notes: Transponders 3 to 5 and 11 to 13 may each be switched to either of two transmit bands, but not to both simultaneously.

Transponders above and below the lines are on different polarizations.

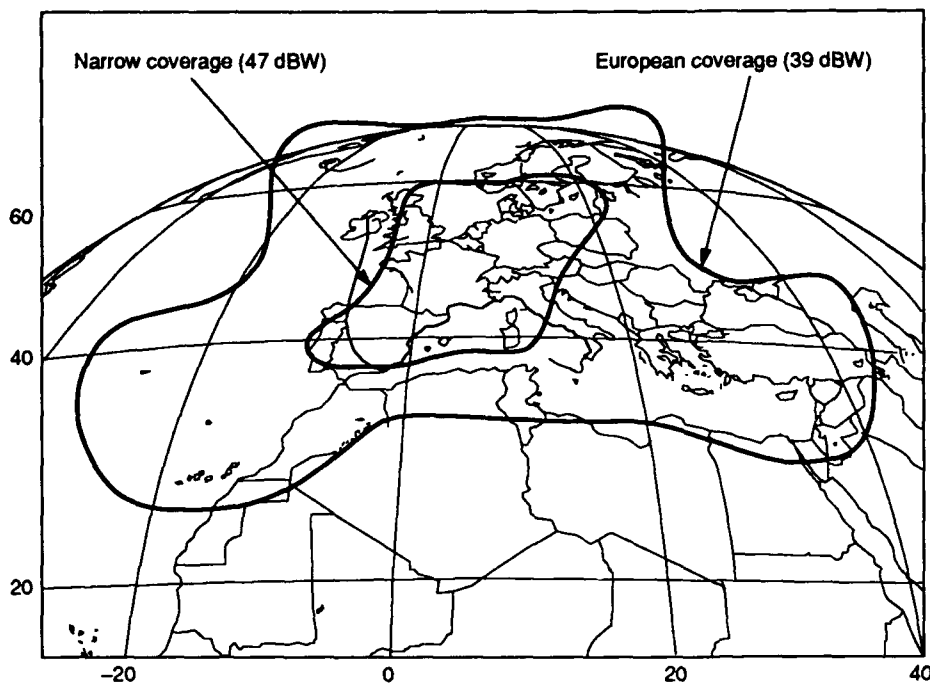
The a, b, c labels identify three groups of transponders, each group may be switched to either the wide or narrow coverage transmit beams.

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Eutelsat II communication subsystem.



Eutelsat II coverage areas.

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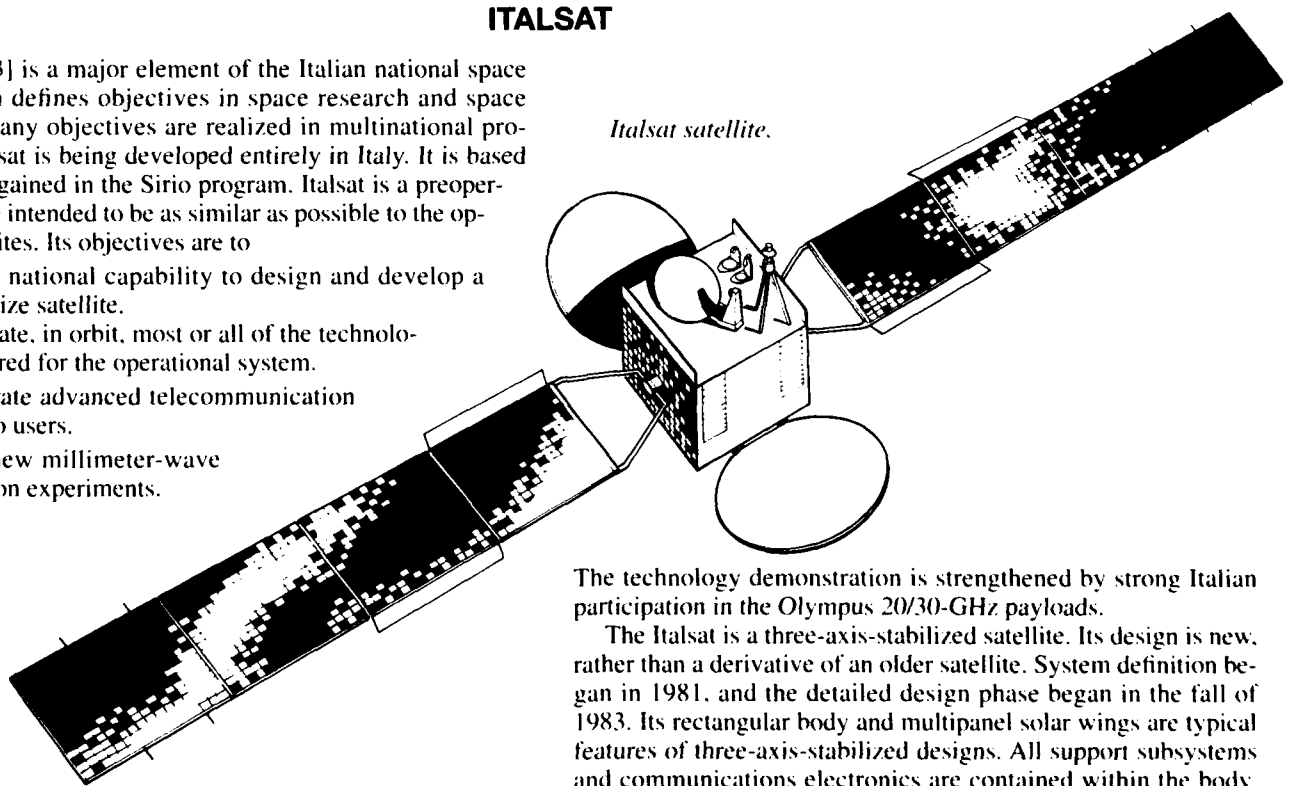
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ITALSAT

Italsat [1-23] is a major element of the Italian national space plan. The plan defines objectives in space research and space technology. Many objectives are realized in multinational programs, but Italsat is being developed entirely in Italy. It is based on experience gained in the Sirio program. Italsat is a preoperational satellite intended to be as similar as possible to the operational satellites. Its objectives are to

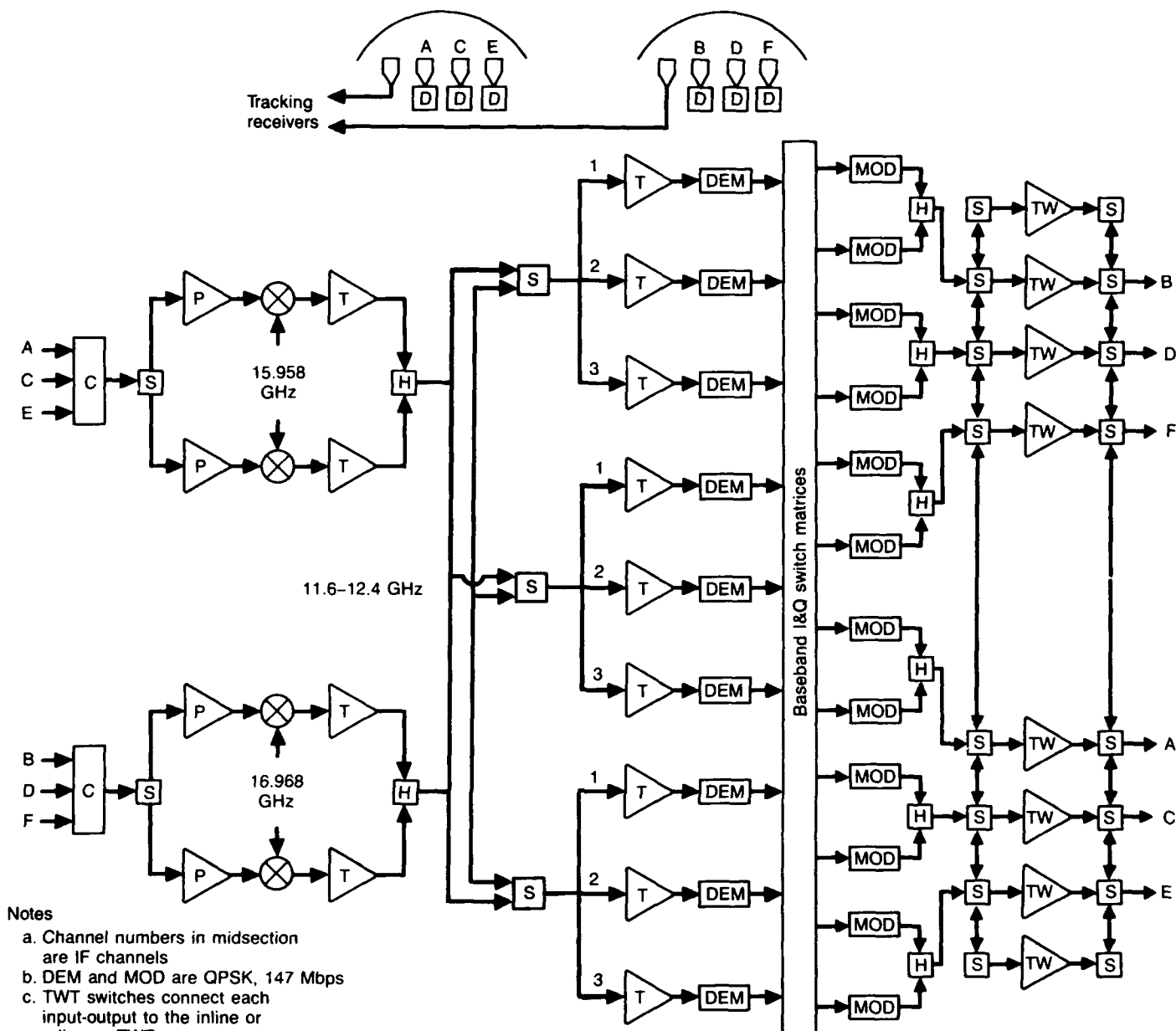
- Prove the national capability to design and develop a medium-size satellite.
- Demonstrate, in orbit, most or all of the technologies required for the operational system.
- Demonstrate advanced telecommunication services to users.
- Support new millimeter-wave propagation experiments.

Italsat satellite.



The technology demonstration is strengthened by strong Italian participation in the Olympus 20/30-GHz payloads.

The Italsat is a three-axis-stabilized satellite. Its design is new, rather than a derivative of an older satellite. System definition began in 1981, and the detailed design phase began in the fall of 1983. Its rectangular body and multipanel solar wings are typical features of three-axis-stabilized designs. All support subsystems and communications electronics are contained within the body. The propulsion subsystem is a bipropellant type and is used both for the apogee maneuver and in orbit. The power subsystem uses



Notes

- Channel numbers in midsection are IF channels
- DEM and MOD are QPSK, 147 Mbps
- TWT switches connect each input-output to the inline or adjacent TWT
- Local oscillator inputs to modulators are not shown

Italsat domestic communication payload.

nickel-hydrogen batteries. The two large antennas are folded against the satellite body for launch and deployed in orbit; each has a positioning mechanism for fine pointing control. The other antennas are fixed to the satellite; their pointing is set by the satellite attitude.

Italsat has three payloads. The largest is for point-to-point domestic communications. This payload will be used for high-volume telephony between major nodes of the Italian terrestrial network. The second payload is for specialized services. This refers to business communications, including voice, data, and facsimile transmissions between small ground terminals at customer locations. The smallest payload is for propagation measurements. Payload and satellite parameters are as follows:

Satellite

Rectangular body, 70 × 70 × 76 in., satellite height (body plus antennas) 11.4 ft, span across deployed antennas 19.2 ft, span of solar arrays 69 ft

Approximately 1900 lb in orbit, beginning of life

Solar cells and NiH₂ batteries, 1600 W minimum after seven years (sunlight), 1100 W (eclipse)

Three-axis-stabilized using pitch bias momentum wheels, ±0.15-deg accuracy; multibeam antennas pointed to ±0.03 deg via tracking of ground beacon

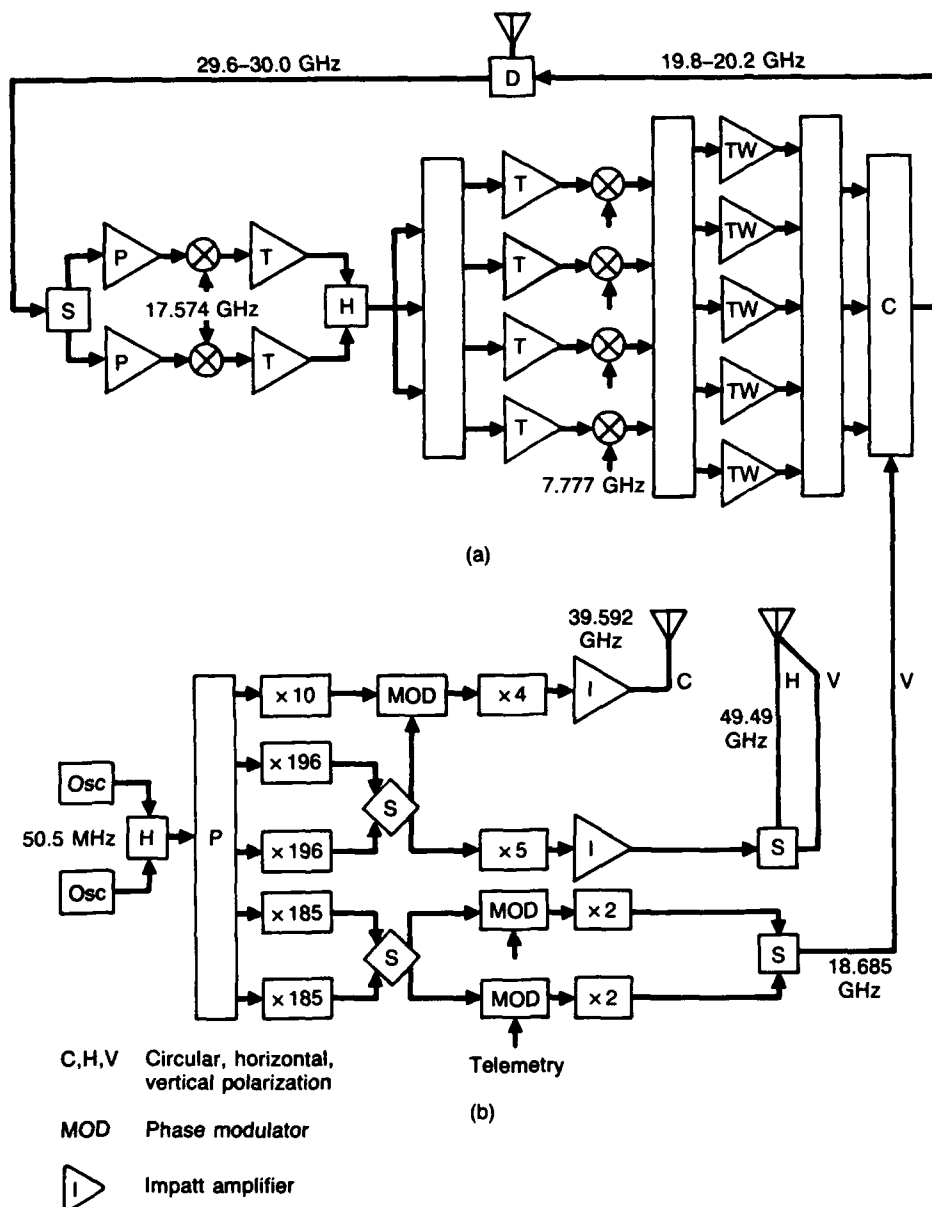
Unified bipropellant propulsion for apogee maneuver and on-orbit control

Configuration

DC (point-to-point domestic communications payload): six 147-Mbps regenerative repeaters

SS (specialized services payload): three 36-MHz bandwidth double-conversion repeaters (only one on during eclipse)

PE (propagation experiment): beacons at 18.7, 39.6, and 49.5 GHz



Italsat. (a) special services; (b) propagation payloads.

Transmitter

DC: 18.82, 19.04, 19.15, 19.48, 19.83, and 20.07 GHz

One 20-W TWT per repeater plus two spares

ERP 57 dBW

SS: 19.72, 19.95, and 20.18 GHz

One 20-W TWT per repeater, plus two spares

ERP 46.2 dBW

PE: 18.685 GHz, 0.1 W, ERP 23.7 dBW

39.592-GHz, 1-W Impatt amplifier, ERP 27 dBW

49.49-GHz, 1-W Impatt amplifier, ERP ≥ 25 dBW

Receiver

DC: 27.61, 27.84, 28.27, 28.62, 28.95, and 29.28 GHz plus tracking beacons at 28.463 and 29.473 GHz

Redundant receivers (one active, one spare) for each antenna

G/T +16 dB at edge of coverage

SS: 29.517, 29.747, and 29.977 GHz

Redundant receivers (one active, one spare)

G/T +5.5 dB at edge of coverage

Antenna

DC: two 77-in.-dia. offset-fed parabolic reflectors, each has three feed horns each generating one 0.49-deg transmit beam and one 0.31-deg receive beam, plus a seven-horn cluster for tracking a ground beacon; edge of coverage is the -3 dB transmit contour and -6 dB receive contour, linear polarization

SS: one 35- \times 25-in. Cassegrain antenna generating one transmit and receive beam approximately 1.3 \times 1.8 deg, linear polarization

PE: two offset-fed parabolic reflectors, one 8-in.-dia. at 40 GHz, one 6-in.-dia. at 50 GHz, 3.3-deg beam, circular polarization at 40 GHz, linear at 50 GHz (can be switched between horizontal and vertical at 933 Hz)

Design life

Seven years

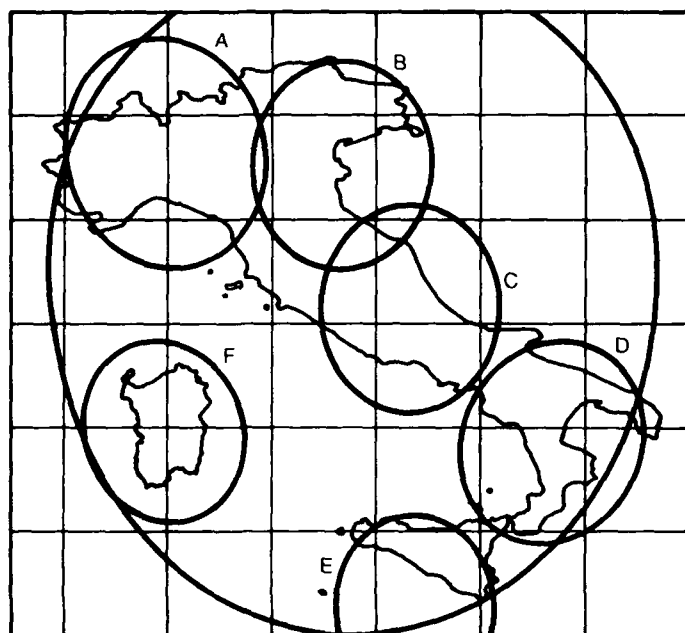
Orbit

Synchronous equatorial, 13°E longitude, stationkeeping to $\pm 0.1^\circ$ N-S and E-W

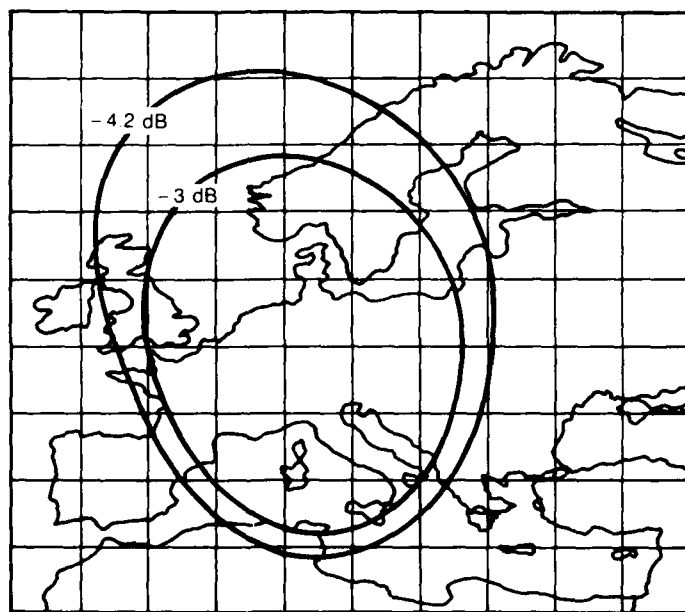
Orbital history

Launched 15 January 1991

Ariane launch vehicle



(a)



(b)

Italsat coverages. (a) Domestic communications (spots A-F) and special services; (b) propagation experiment.

Management

Developed by Telespazio and Selenia for Italian Space Agency (through 1988 development was managed by Italian National Research Council)

The 20/30-GHz domestic communications payload includes uplink demodulation, baseband-switched TDMA, and remodulation. The TDMA scheme uses 32-msec frames with 3000 slots per frame. The satellite generates the system timing reference. Each of the two large antennas generates three spatially separated beams, which are used for both transmission and reception. The TDMA switching can accommodate up to sixteen ground terminals in each beam. Every beam uses a separate frequency, although spatial reuse of frequencies is being considered for the operational system. The same frequency pattern is used in each antenna. Hence, only two local oscillator frequencies convert the uplinks to a common set of three intermediate frequencies at about 12 GHz. The signals are then routed to 147.456-Mbps QPSK demodulators, baseband switches, and 147.456-Mbps QPSK modulators operating at the downlink frequencies. Downlinks are continuous TDM combinations of uplink bursts. The modulator outputs are routed to the redundant TWTs. In addition to the communications receivers, the payload has tracking receivers for each antenna. These derive pointing information that is used to control the antenna positions.

The specialized services payload also operates in the 20- and 30-GHz bands. It has one antenna generating a single beam which includes all of Italy. The payload has three channels, each with a 36-MHz bandwidth. Only one is used during eclipse. The redundant broadband receivers downconvert the signals to intermediate frequencies near 12 GHz. Channelized IF amplifiers are followed by upconverters and TWTs, all with some redundancy. Transmissions will be QPSK at a TDMA burst rate of 24.576 Mbps, with frequency hopping among the channels. This TDMA rate is exactly one-sixth the rate in the main payload. The possibility of interconnecting high- and low-rate channels with rate conversion is being studied for the operational satellites that will follow Italsat. Both payloads will be used with ground terminals that have antenna diameters of either 11.5 or 16.5 ft, depending on local rainfall statistics.

The propagation experiments payload generates three signals, near 20, 40, and 50 GHz, from a common oscillator. The 40- and 50-GHz frequencies were selected, because there are several international allocations for communications and broadcasting satellites near these two frequencies. The 20-GHz signal is modulated by an 8-kHz subcarrier carrying spacecraft telemetry data and is radiated through the antenna of the specialized services payload. It serves as a tracking beacon for all Italian ground terminals using the satellite. The received power level can be used as a measure of propagation loss for uplink power control. The 40-GHz beacon is phase modulated by a 505-MHz sine wave to produce two sidebands and is transmitted to most of Europe. The 50-GHz beacon has the same European coverage. It is unmodulated but can be switched between orthogonal linear polarizations at 933 Hz. Propagation measurements planned in Italy include attenuation, depolarization, wavefront coherence, and other phenomena.

The engineering model of Italsat was integrated and tested in 1988. The flight model finished testing in 1990 and was launched in January 1991. Initial post-launch behavior was very good. An extended period of testing is planned, followed by operational use of the satellite beginning in summer 1991.

Although higher capacity future satellites have been studied, none has been authorized. However, to continue the program, production of a second flight model Italsat was authorized at the end of 1990. No launch date has been set for this satellite.

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TELECOM 2

The Telecom 2 satellites [1] are being developed to replace the Telecom 1 satellites. The contractors were chosen near the end of 1987, and a contract was signed in the spring of 1988. It is for three satellites, with an option for a fourth. The Telecom 2 satellites are larger than Telecom 1 but of a similar design. They are larger and have more power-generating capability, to support larger communications payloads. These payloads are the same in number and missions as on Telecom 1 but have more, and higher power, transponders.

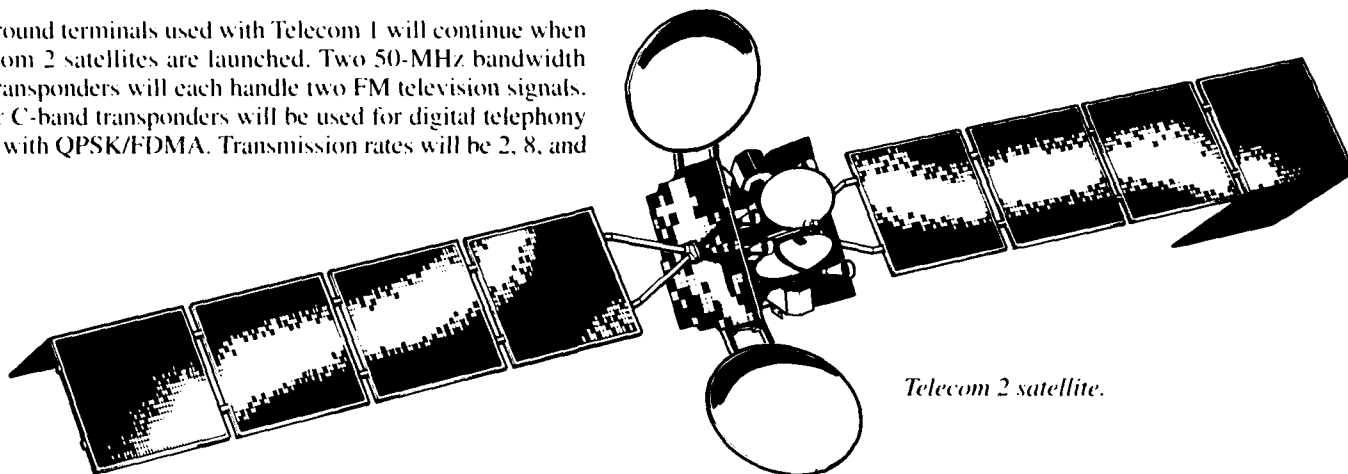
The C-band payload uses 4 and 6 GHz for communications between France and its overseas departments. On Telecom 2, this payload has six transponders for spot beams to France, Guiana and the West Indies, and the islands of St. Pierre and Miquelon (near Newfoundland). Four other transponders are connected to a semi-global beam covering Guiana, St. Pierre, and France as well

as Reunion in the Indian Ocean (near Madagascar). These transponders use the two large reflectors which are deployed in orbit from the sides of the satellite body.

The X-band payload extends the Syracuse system begun with Telecom 1. It has five transponders and provides service to French forces inside France and via global beams to all points visible from the satellite and via a steerable antenna on the earth-viewing face of the satellite.

The Ku-band payload is for voice, videoconferencing, and business networks in France. It can also be used in neighboring countries with larger ground antennas. Capacity has almost doubled from Telecom 1 by the use of two polarizations for transmission and reception rather than one on Telecom 1. This payload's antenna is on the earth-viewing face of the satellite; its beam covers France and the neighboring countries.

The ground terminals used with Telecom 1 will continue when the Telecom 2 satellites are launched. Two 50-MHz bandwidth C-band transponders will each handle two FM television signals. The other C-band transponders will be used for digital telephony and data, with QPSK/FDMA. Transmission rates will be 2, 8, and



Telecom 2 satellite.

34 Mbps, with up to eight carriers per transponder. Transmissions in Ku-band transponders will be QPSK/TDMA at 49 Mbps.

Additional Telecom 2 details are as follows:

Satellite

Rectangular body, height of body plus antennas 10 ft, span of deployed antennas 24 ft, span of deployed solar arrays 72 ft

2215 lb in orbit, beginning of life

Sun-tracking solar arrays and NiH_2 batteries, 3575 W at end of life

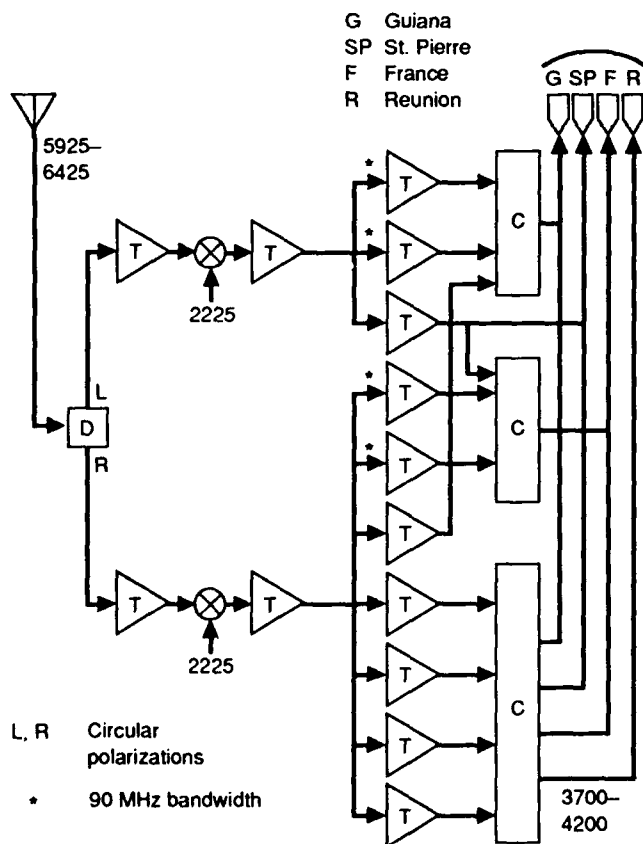
Three-axis stabilization using momentum wheels and magnetic torquer, 0.1-deg pointing accuracy

Unified bipropellant liquid propulsion for apogee maneuvers and on-orbit use

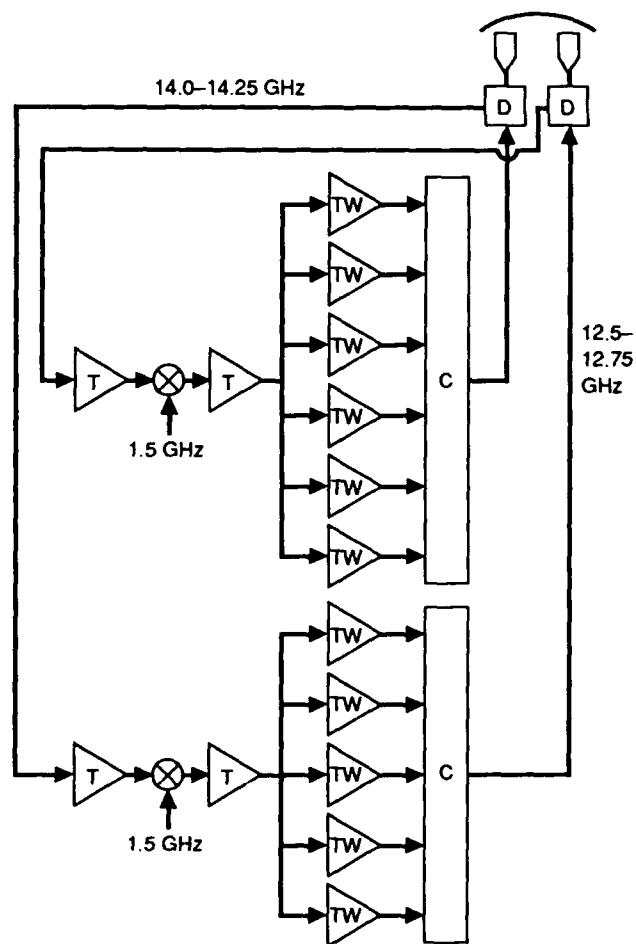
Configuration

C: four 90-MHz bandwidth transponders and six 50-MHz bandwidth transponders, partial dual-polarization frequency reuse

X: three 40-MHz, one 60-MHz, and one 80-MHz bandwidth transponders



Telecom 2 communication subsystem, C-band.



Telecom 2 communication subsystem, Ku-band.

Ku: eleven 36-MHz bandwidth transponders, dual-polarization frequency reuse

Transmitter

C: in 3.7- to 4.2-GHz band

One 10-W solid-state power amplifier per transponder plus four spares

ERP over coverage areas 39 dBW (spot beams), 32.5 dBW (semi-global beam)

X: in 7.25- to 7.75-GHz band

One 40-W TWTA for each of two transponders plus one spare

One 20-W TWTA for each of three transponders plus two spares

Ku: 12.5 to 12.75 GHz

One 55-W TWTA per transponder plus four spares
ERP 52.5 dBW over all of France

Receiver

C: 5.925- to 6.425-GHz

G/T -12 dB/K

X: in 7.9- to 8.4-GHz band

Ku: 14.0 to 14.25 GHz

G/T 4 dB/K

Antenna

C: two 7.2-ft-dia. deployed offset-fed parabolic reflectors with four feed horns (transmit), earth coverage horn (receive)

X: earth coverage horns for transmission and reception plus one steerable offset-fed parabolic reflector for transmission only

Ku: one dual-gridded offset-fed parabolic reflector, dual orthogonal linear polarizations

Design life

Ten years, two months

Orbit

Synchronous equatorial

Orbital history

2A: launch scheduled December 1991 or early 1992

2B: launch scheduled spring 1992

Ariane launch vehicle

Management

Developed for France Telecom (French Ministry of Post, Telecommunications and Space) and Délégation Générale pour l'Armement (DGA, French Ministry of Defense) by Matra (spacecraft) and Alcatel Espace (payload)

Operated by France Telecom and DGA

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1. P. Ramat, et al., "The Second Generation of Digital Networks in the French Domestic Satellite System," *8th International Conference on Digital Satellite Communications* (April 1989).

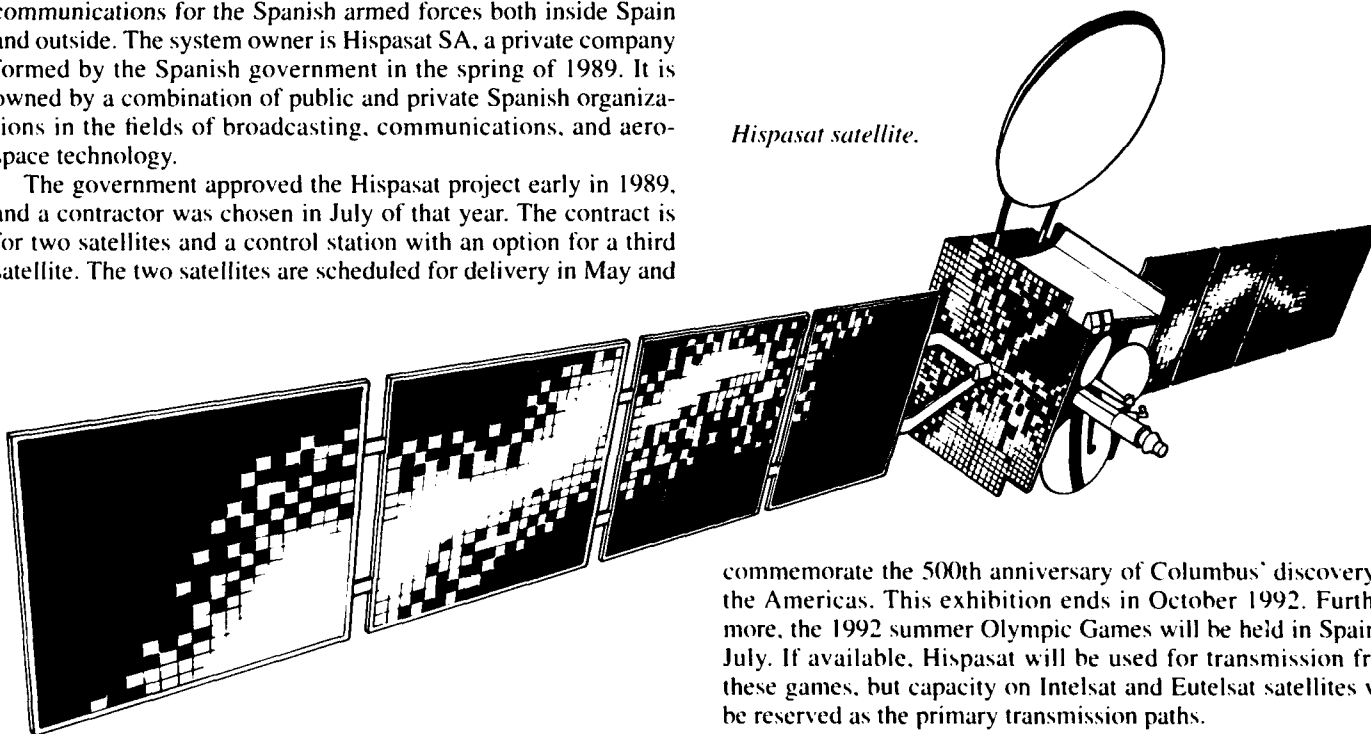
HISPASAT

Hispasat [1-3] is a satellite system being developed by Spain. It will provide television broadcasting to homes, television distribution, and communications services to Spain and the Canary Islands; television distribution to the Americas; and communications for the Spanish armed forces both inside Spain and outside. The system owner is Hispasat SA, a private company formed by the Spanish government in the spring of 1989. It is owned by a combination of public and private Spanish organizations in the fields of broadcasting, communications, and aerospace technology.

The government approved the Hispasat project early in 1989, and a contractor was chosen in July of that year. The contract is for two satellites and a control station with an option for a third satellite. The two satellites are scheduled for delivery in May and

September 1992. It is planned that the first satellite be in orbit by July 1992 and fully operational by August. The schedule is of great importance, because the system is to be used for transmissions from the international exhibition to be held in Seville to

Hispasat satellite.



commemorate the 500th anniversary of Columbus' discovery of the Americas. This exhibition ends in October 1992. Furthermore, the 1992 summer Olympic Games will be held in Spain in July. If available, Hispasat will be used for transmission from these games, but capacity on Intelsat and Eutelsat satellites will be reserved as the primary transmission paths.

The satellite is a three-axis-stabilized design, with solar arrays extending from a central body. The technology for the satellite and its payloads has been demonstrated in other European satellites. The challenging aspect of Hispasat is to integrate the payload elements necessary to accomplish the five missions listed in the first paragraph. The large reflector deployed to one side of the satellite body is for television broadcasting. Antennas no larger than 2-ft diameter will be required to receive these broadcasts in Spain and the Canary Islands. The smaller antennas on the satellite body are for the television distribution, communications, and military communications missions.

The television distribution and communications missions also are for Spain and the Canary Islands. They will use ground antennas with diameters between 3 and 15 ft. These missions, and the television broadcasting, can be used in other parts of Europe and North Africa with larger ground antennas. The military mission includes a global coverage antenna on the satellite and a steerable spot beam. This mission will support both land and naval forces in Europe and North Africa and the adjacent ocean areas.

Approximately one-third of the satellite hardware, as well as a majority of the related ground equipment, are being built by Spanish companies. Preliminary satellite characteristics are:

Satellite

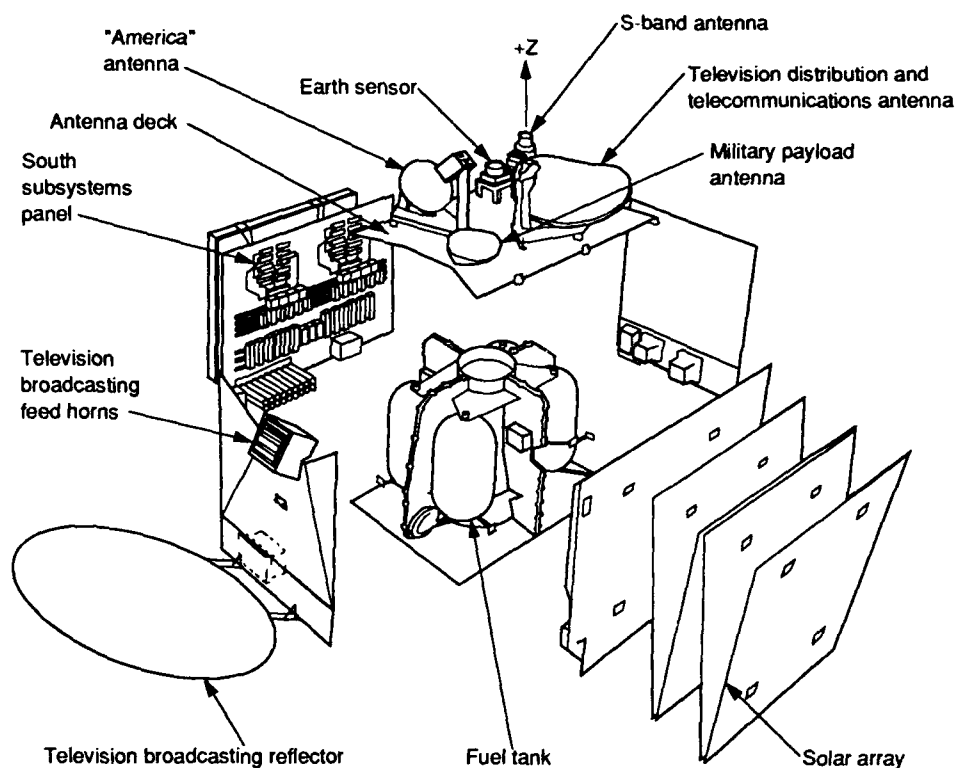
Body approximately 6 × 6 × 7 ft, span of solar array 69 ft
 Approximately 2300 lb in orbit, beginning of life
 Sun-tracking solar arrays and NiH₂ batteries, approximately 3600 W beginning of life
 Three-axis-stabilized using momentum wheels and magnetic torquer, approximately 0.1-deg accuracy
 Unified bipropellant liquid propulsion for apogee maneuver and on-orbit use

Configuration

DB: three 27-MHz bandwidth transponders for television broadcasting to homes
 TV-S: three 72-MHz bandwidth transponders for television distribution to larger antennas in Spain and the Canary Islands
 TV-A: one 36-MHz bandwidth transponder for television distribution to larger antennas in the Americas
 TC: five 72-MHz bandwidth transponders for telecommunications in Spain and the Canary Islands
 M: one 40-MHz bandwidth transponder for military telecommunications

Transmitter

DB: in the band 12.1 to 12.5 GHz
 Three 11-W TWTAs active, two spares
 ERP per transponder 58 dBW over Spain and the Canary Islands, 51 dBW as far as England, Germany, and most of Italy



Hispasat satellite details.

TV-S: in the band 10.7 to 11.7 GHz

Three 55-W TWTAs active, two spares

ERP per transponder 52 dBW over Spain and the Canary Islands, 45 dBW as far as Southern England, France, Italy, and Morocco

TV-A: in the band 11.7 to 12.2 GHz

One 110-W TWTA active, one spare

ERP 42 to 48 dBW over Central and South America (except Brazil), the Caribbean, and the eastern time zone of the United States

TC: in the band 10.7 to 11.7 GHz

Five 55-W TWTAs active, two spares

ERP per transponder 52 dBW over Spain and the Canary Islands, 45 dBW as far as Southern England, France, Italy, and Morocco

M: in the band 7.25 to 7.75 GHz

One 40-W TWTA active, one spare

Receiver

DB: in the band 17.3 to 18.1 GHz

G/T 12 dB/K

TV-S: in the band 14.0 to 14.5 GHz

G/T 6 to 9 dB/K

TV-A: in the band 14.0 to 14.2 GHz

TC: in the band 14.0 to 14.5 GHz

G/T 6 to 9 dB/K

M: in the band 7.9 to 8.4 GHz

Antenna

DB: one deployed offset-fed parabola

TV-S: one offset-fed parabola

TV-A: one offset-fed parabola

TC: shared with TV-S

M: one steerable parabola (spot beam) and two horns (global beam transmit and receive)

Design life

Ten years

Orbit

Synchronous equatorial, 31°W longitude, stationkeeping to $\pm 0.1^\circ$ N-S and E-W

Orbital history

1A: launch planned by July 1992

1B: launch planned by late 1992

Ariane launch vehicle

Management

Developed for Hispasat SA by Matra with British Aerospace (spacecraft) and Marconi (payload) as primary subcontractors

Operated by Hispasat SA

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1. "Hispasat et la Cooperation Franco-Espagnole," *Air & Cosmos*, No. 1253 (7 Octobre 1989).
2. S. Chenard, "Hispasat, Europe's Most Urgent Satellite," *Space Markets*, Vol. 5, No. 4 (September-October 1989).
3. I. Parker, "Spain Buys Satellites," *Space*, Vol. 5, No. 5 (September-October 1989).

TURKSAT

In the fall of 1990, the government of Turkey announced the award of a contract for Turksat. This satellite will serve Turkey and other regions in Europe which have Turkish language residents. The contract includes two satellites launched and delivered in orbit, and a ground control center.

The satellite will have sixteen transponders; the desired ERP is

52 dBW. The satellite will be three-axis-stabilized with deployed solar arrays. A single large reflector will be deployed as part of the antenna that forms a beam, or beams, which cover the desired service area. The satellite size will be on the order of 2400 lb in orbit. The first launch is planned in 1993 on an Ariane; more likely, it will occur in 1994.

EUROPEAN SATELLITE BROADCASTING

High-power broadcasting from satellites exists in Europe on the German TV-Sat, French TDF, and one payload of ESA's Olympus. The British satellite, BSB, is in orbit but unused. Eutelsat's Eutelsat I satellites and Luxembourg's Astra 1A and 1B are heavily used for television distribution to cable systems. Signals from these systems also are received on individual home receivers, but they require antennas larger than the less than 2-ft diameter characteristic of high-power broadcasting systems.

The limit on the high-power systems has been the cost of the satellites and the programming. The trend in Europe is in the direction of Eutelsat and Astra: more channels per satellite and Pan-

European coverage. Consumers apparently prefer the quantity of programming on these systems and are willing to buy the antenna sizes required to receive from them. Both systems are introducing higher-power satellites—the Eutelsat II series now and Astra 1C and 1D in a few years.

Eutelsat has been studying satellites optimized for European broadcasting. In 1990, the Eutelsat member nations agreed in a general way to proceed with this type of satellite, usually called Europesat. Specific requirements for Europesat will be developed in 1991, and a Eutelsat request for proposals could be issued in 1992. If so, the first satellite could be launched in 1997.

ESA DATA RELAY SATELLITE

Since 1986, ESA has been conducting studies and technology development in preparation for building a data relay system [1-5]. The central part of this system will be two data relay satellites in synchronous orbit. Benefits to low-orbit satellites using these relays are a result of the nearly continuous contact available between the low-orbit satellites and their control centers. These benefits include transfer of data at rates too high for on-board recording, scheduling and control not tied to infrequent passes over ground stations, and satellite simplification since less autonomy is required. Candidate users of this data relay system are the European portion of an international space station, European remote sensing satellites, and launch operations.

Two major in-orbit demonstrations are part of the data relay preparation program. The first is a relay satellite demonstration using the Olympus satellite and a low-orbit satellite called Eureka (European Retrieval Carrier). The second is the S-band multiple-

access and laser communications payloads on the ESA Artemis satellite, which was described in the section on experimental satellites.

The Eureka demonstration will use the 20/30-GHz communications payload on Olympus. This payload has two transponders, one for transmissions from Eureka to the ground and one for the opposite direction. The payload also has two antennas: one will be pointed at the ground and one at Eureka. The inter-orbit communication payload on Eureka uses a 21-in. antenna and a 10-W TWTA; because of the small antenna, the maximum transmission rate is 2 Mbps. The rate to Eureka will be 2 kbps. Eureka is scheduled to be launched in the summer of 1992 on the Shuttle and to be retrieved by a Shuttle mission six to twelve months later.

The data relay system is expected to use both S-band and Ka-band (23-28 GHz) for links between the relay satellite and low-orbit satellites. The S-band will have multiple access capabilities

and be interoperable with the NASA TDRSS S-band multiple access service. The Ka-band communications will have characteristics chosen in coordination with NASA, for interoperability with Advanced TDRSS, and with Japan, for interoperability with their proposed relay satellite. Inclusion of optical communication on the relay is uncertain.

In June 1990, ESA approved the next step of the data relay program. If it proceeds as planned and the satellite development is funded, the first relay satellite could be launched in 1996 or 1997.

* * * * *

1. E. W. Ashford, D. L. Brown, and K. G. Lenhart, "The ESA Data-Relay Satellite Programme," *ESA Bulletin*, No. 47 (August 1986).
2. A. Dickinson, S. E. Dinwiddy, and J. Sandberg, "The European Data Relay System as Part of the In-Orbit Infrastructure," *ESA Bulletin*, No. 51 (August 1987).
3. J. P. Pouliquen and R. Tribes, "Inter Orbit Communication (IOC)," *Space Technology*, Vol. 9, No. 4 (1989).
4. G. Oppenhäuser, "ESA's First Data-Relay Satellite Experiment," *ESA Bulletin*, No. 47 (August 1986).
5. A. Dickinson, "The Data-Relay Preparatory Programme," *ESA Bulletin*, No. 61 (February 1990).

DOMESTIC AND REGIONAL SATELLITES

Domestic and regional satellites are now described for all countries except Canada, the United States, and Europe. Asia, Africa, Australia, and Central and South America are all represented. Only India and China have developed communication satellites themselves, and these have been rather small. Japan launched a domestically developed experimental communication satellite, ETS-V, in 1987. Japan and India have both purchased their primary satellites from the United States, although both are working also to develop their internal capabilities. The other countries have purchased their satellites from United States, Canadian, and European manufacturers.

A common purpose, for the satellites described here, is to overcome natural barriers to communications, e.g., deserts, mountains, dense forests, and oceans. The benefits of the satellite

systems include much lower cost than terrestrial alternatives and the ability to provide nationwide communications. Many countries have coupled the satellite purchase with internal technological development. Examples are building earth terminals and receiving training in satellite operation and earth terminal maintenance. Of the satellites discussed here, only Arabsat is a regional satellite—a single system providing communications among many nations with a common interest. The others are all domestic satellites, although Indonesia leases some transponders to neighboring countries for their domestic use. Many other nations lease satellite capacity from Intelsat either because their needs are too small to justify a whole satellite, or as an initial step to their own satellite system. The Intelsat leases were described earlier.

JAPAN (Government Programs)

In Japan, the National Space Development Agency (NASDA) has the responsibility for launch vehicle and applications satellite developments [1-6]. Although the applications programs are varied, the major emphasis has been on communications. The specific programs are the Communication Satellites, the Broadcasting Satellites, and the experimental satellites (described earlier). At the beginning of 1985, a change of government policy permitted private communication systems to operate in Japan. These systems are described in the next section.

The emphasis on space communications is a result of the crowding of extensive existing communications facilities in urban areas and the difficult geographic problems (islands and mountains) of the nonurban areas of the country. Considerable terrestrial use of the lower microwave frequencies has led to extensive efforts to investigate higher frequencies. Consequently, most of the communications equipment in these programs operates at frequencies between 10 and 35 GHz.

NASDA's satellite communications development effort is designed to make economic use of available foreign technology while developing internal technical capabilities. Thus far, all satellites have been built by United States companies under contract to Japanese companies, but all ground terminals have been developed in Japan. The percentage of Japanese-built equipment in the satellite is increasing, particularly in the communication subsystems.

* * * * *

1. F. Ikegami and S. Morimoto, "Plans for the Japanese Domestic Satellite Communication System," Paper 4G.1, 1972 *IEEE Intercon Record* (March 1972).

2. M. Hirai, et al., "Development of Experimental and Applications Satellites," *Acta Astronautica*, Vol. 7, No. 8-9 (August-September 1980).
3. *Aviation Week & Space Technology* (13 August 1973), p. 19; (4 March 1974), p. 16; (22 April 1974), p. 23; (17 March 1975), p. 61; (1 March 1976), p. 52; (4 October 1976), p. 24; (17 October 1977), p. 104; (3 March 1980), pp. 92, 234; (9 March 1981), p. 107; (10 August 1981), p. 61; (8 March 1982), p. 107; (5 April 1982), p. 13; (26 April 1982), p. 15; (31 January 1983), p. 23; (14 March 1983), p. 112; (11 April 1983), p. 86; (30 January 1984), p. 19; (13 February 1984), p. 125; (21 May 1984), p. 18; (23 July 1984), p. 72; (17 September 1984), p. 20; (3 June 1985), p. 72; (24 June 1985), p. 15; (19 August 1985), p. 13; (25 November 1985), p. 13; (6 January 1986), p. 21; (20 January 1986), p. 25; (24 February 1986), p. 66; (10 March 1986), p. 138; (9 June 1986), p. 29; (7 July 1986), p. 27; (11 July 1988), p. 11; (19 December 1988), p. 11; (26 February 1990), p. 32; (12 March 1990), p. 53; (16 April 1990), p. 28; (10 September 1990), p. 30.
4. R. Hayaski, Y. Furuhashi, and N. Fugono, "Propagation Characteristics for Millimeter and Quasi-Millimeter Waves by Using Three Japanese Geostationary Satellites," *Acta Astronautica*, Vol. 7, No. 11 (November 1980).
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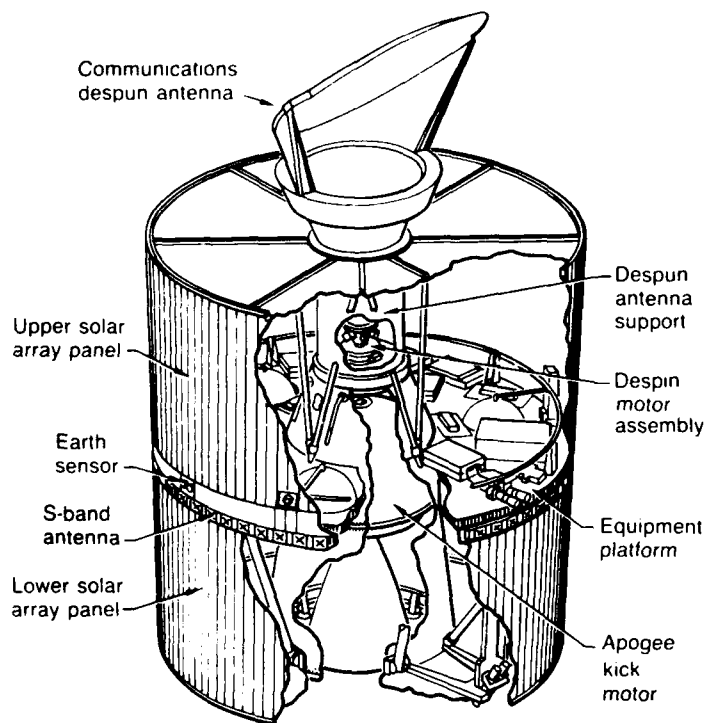
Communications Satellites (CS, CS2, CS3)

The objectives of the Communications Satellite program [1-29] are to

- Provide, in combination with terrestrial facilities, high-capacity links between urban centers.
- Provide new and/or improved services to small islands located away from the primary islands of Japan.
- Be available as an alternate transmission path for any terrestrial facilities damaged by natural disasters.

The program uses two frequency bands, 4/6 GHz and 20/30 GHz. The latter band supports the first objective; the former supports the second. Both bands are available for emergency use. The program includes three generations of satellites, CS and CS2, and a third, CS3, in use.

The first phase of the program was based on the Medium Capacity Communications Satellite for Experimental Purpose, commonly called the CS. The CS, launched in 1977, was used for a



Japanese communication satellite (CS, CS2).

variety of tests and preoperational system demonstrations. Activities included transponder characterization, tests of several transmission and multiple access techniques, gaining satellite control experience, and propagation measurements. After launch, the CS was renamed *Sakura*, which translates to *Cherry Blossom*. (The Japanese typically name satellites, which successfully reach orbit, after flowers.)

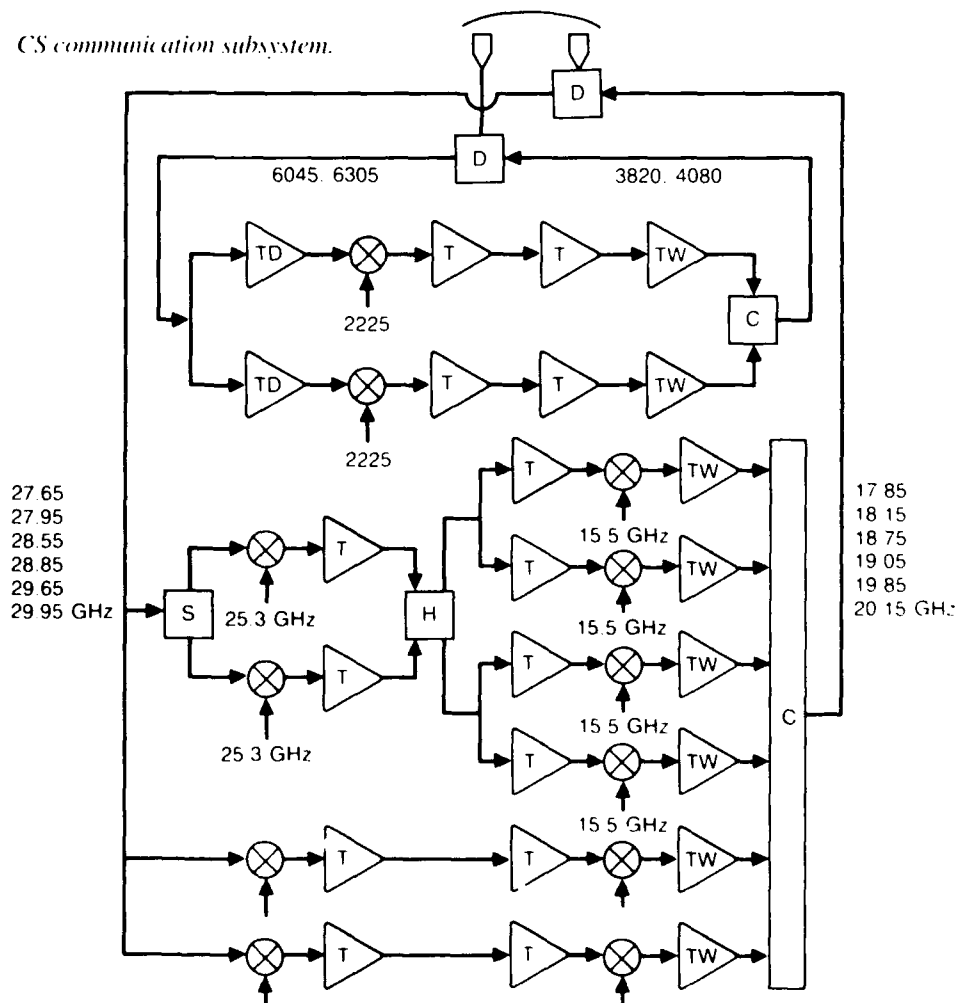
The satellite was spin-stabilized with a despun antenna, very similar to the NATO III satellite. The solar array was identical, and many support subsystems were derived from NATO III subsystems. The communication subsystem and antenna were new designs. This satellite had eight channels, each with a 200-MHz bandwidth. Two channels were in the 4- and 6-GHz band used by many commercial satellites. The other six channels were in the 17.7- to 21.2-GHz and 27.5- to 31-GHz bands. This was the first use of these frequencies for standard communication links, although other satellites had equipment for special transmissions for propagation measurements at these frequencies. They were selected, because the allocated bands at lower frequencies (i.e., 4 to 6 GHz and 11 to 14 GHz) were already heavily used in Japan for terrestrial services, and the resulting interference to satellite links would overly constrain earth terminal locations. The satellite antenna was a despun horn whose axis was coincident with the satellite spin axis. It was me-

chanically despun, and the antenna beam was reflected toward the earth by a reflector oriented 45 deg from the spin axis. The reflector was not exactly flat but was contoured to shape the K-band (20/30-GHz) beam to match the geography of the main Japanese islands. The 4/6-GHz beams used the same antenna but were circular and were of a size that covered all islands to be served by CS.

The CS2 satellites were developed to follow the CS satellite in support of operational communications links. The newer satellites were almost identical to the CS. The CS2 communication subsystem, like the CS, had two 4/6-GHz channels and six 20/30-GHz channels. The bandwidths had been reduced but were still more than adequate for the chosen data rates. The communication subsystem configuration has been modified, primarily to improve reliability. Also, improvements in microwave electronics since the CS was built resulted in some satellite performance increases.

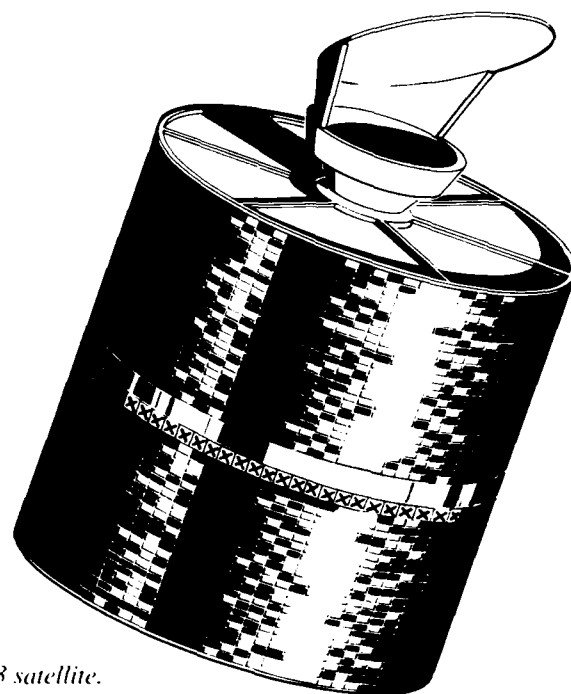
CS2A was launched early in 1983 and was named *Sakura*. CS2B was launched later in 1983. The 4/6-GHz channels were used with a 109-Mbps QPSK TDMA network to transmit telephone and television between Tokyo and remote islands such as Okinawa. The 20/30-GHz channels were used with a 65-Mbps BPSK TDMA network for telephone transmissions between eight major cities. Fixed terminals for these links had 38-ft antennas. Transportable terminals for each frequency band, with about 10-ft-diameter antennas, provided FDMA links. All of these links were for public or governmental communications. Nippon Telephone and Telegraph (NTT), which provides all public communi-

CS communication subsystem.



cations, used both C-band and four K-band channels. Various government agencies and public utilities used the other two K-band channels. Business communications, like those available on the many United States domestic satellites, were not planned until introduction of the CS3 satellites at the end of the 1980s. Only 20% of one K-band channel was allocated for testing business communications. This was a disappointment to many businesses that desired such a service.

The CS3 satellites were developed to continue the communication services started with the CS2 satellites. CS3 provides improved capacity, due both to more transponders and higher performance in each, and greater reliability. The external appearance of these satellites is the same as for CS and CS2. The one major construction difference is that CS3 has two internal equipment shelves. The lower is for mounting support equipment, the upper for the communication subsystem. The other major change on CS3 is the use of GaAs solar cells rather than silicon cells. This is the first use of GaAs cells on any communication satellite. Their benefits, relative to silicon, are 50% greater efficiency at end of life plus lower sensitivity to operating temperature and radiation effects. The increased power permits operation of more transponders. Also, larger batteries permit the use of all transponders in eclipse rather than only two on CS2. The CS-3 communication subsystem has two C-band and ten K-band channels. The C-band section has the same configuration as CS2, but field effect transistor amplifiers have replaced the TWTAs. The K-band section has several changes:



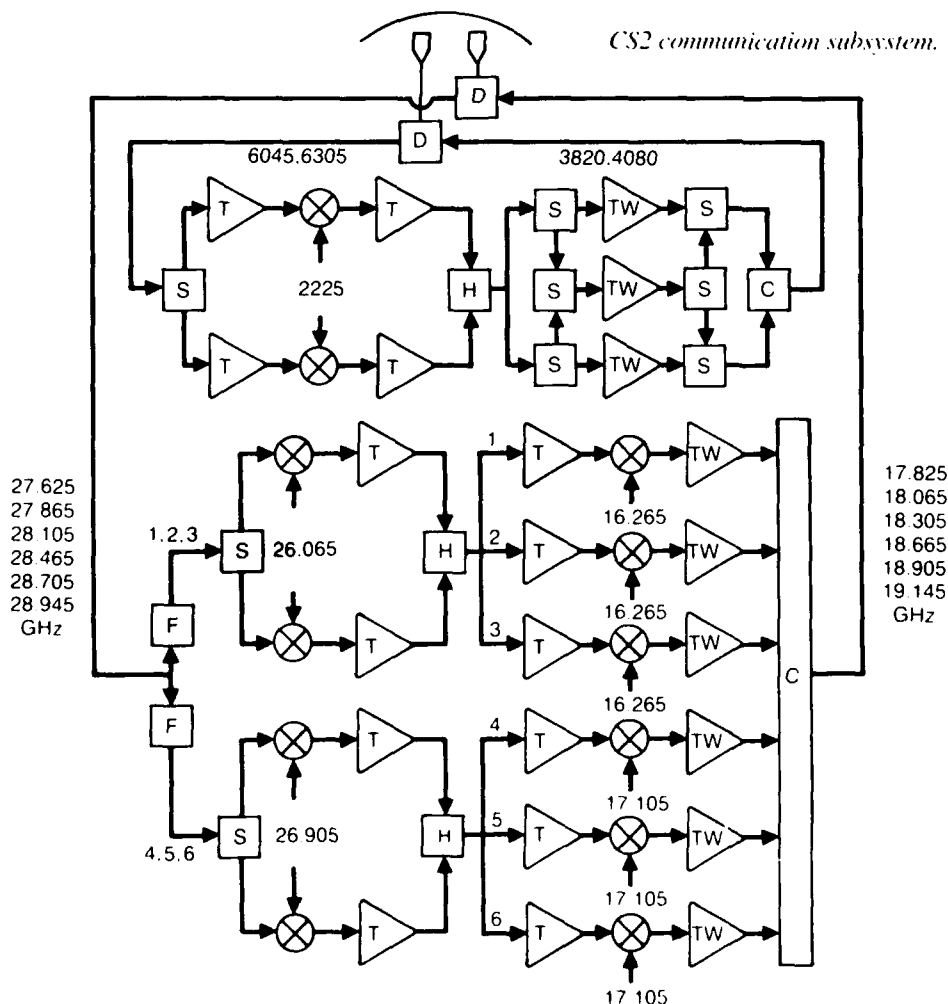
CS3 satellite.

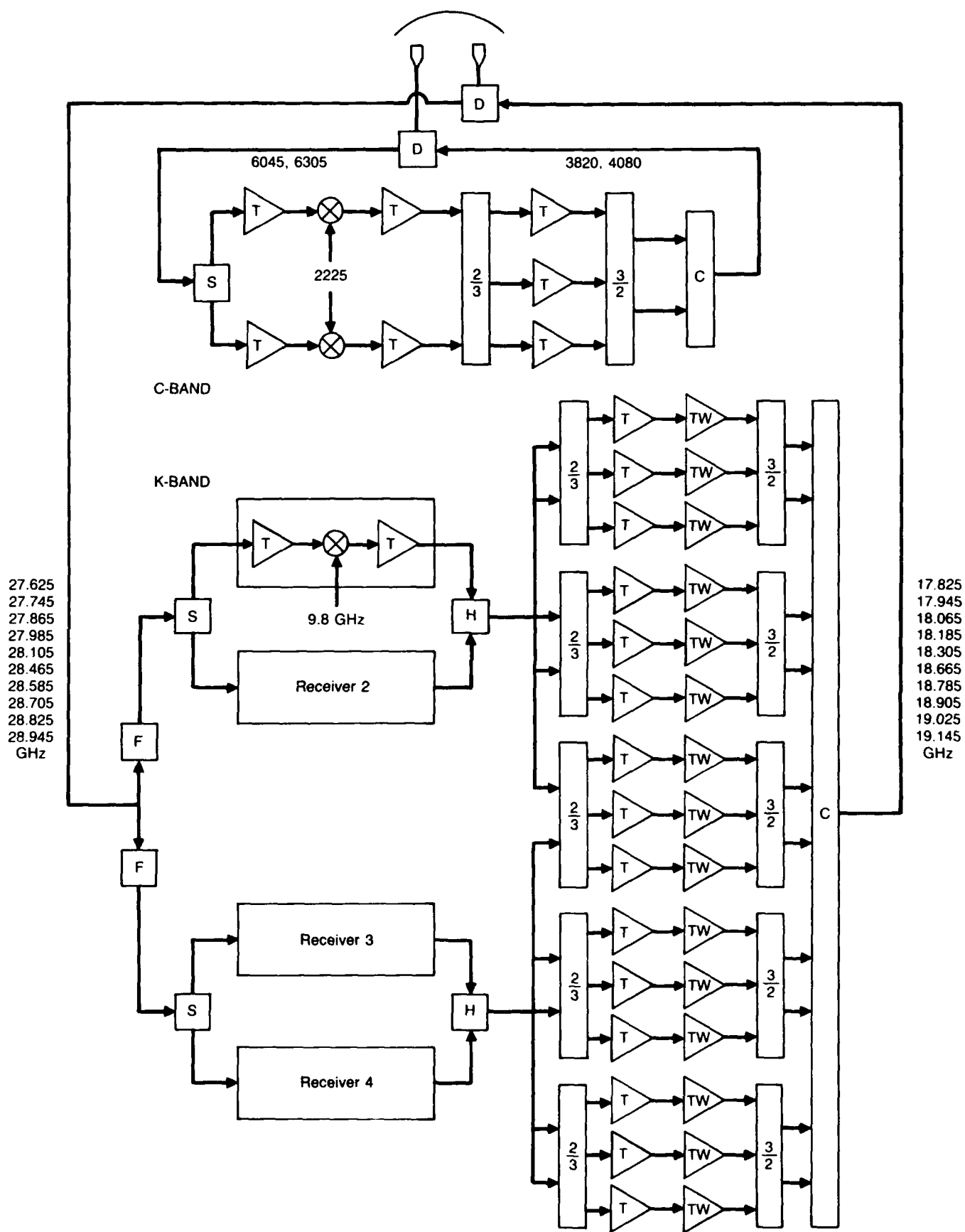
- There are more channels, each with a smaller bandwidth, yet still more than sufficient for the 65-Mbps transmission used with CS2.
- Newly developed GaAs FET preamplifiers at the uplink frequency provide amplification before frequency conversion. This permits a change from double- to single-conversion transponders, with an attendant weight savings and improved performance.
- Transmitter redundancy has been added.

The two CS3 satellites were launched in 1988. They were among the first satellites launched by the Japanese H-1. The applications, transmission formats, and ground stations used with CS2 continued with CS3. These new satellites still were not directed towards business communications, but business users were able to look toward the new private communication satellite systems about to be launched (described in a later section). The CS3 continued to be primarily for government and public communications.

Studies of a CS4 series began prior to the CS3 launches. However, as part of the United States-Japan trade negotiations, the United States argued that CS4 was an operational satellite, not an experimental one, and hence should be procured by open competition. The Japanese reluctantly agreed, and direct plans for CS4 were dropped. Nevertheless, the government will require some new satellite capacity in 1995 to replace the CS3 satellites. To fulfill this need, in summer 1991 NTT requested proposals for a new series of satellites. These satellites will

CS2 communication subsystem.





CS3 communication subsystem.

have transponders using both C-band and K-band, perhaps with an additional S-band payload for service to mobile users. Two launches are planned in 1995.

Details of the CS, CS2, and CS3 satellites are as follows:

Satellite

Cylinder, 86-in. dia., 88-in. (CS)/81-in. (CS2)/92-in. (CS3) height, overall height, 139 in. (CS)/130 in. (CS2)/139 in. (CS3)

Approximately 750 lb (CS)/770 lb (CS2)/1210 lb (CS3) in orbit, beginning of life

Solar cells and NiCd batteries, 529 W (CS)/540 W (CS2) at beginning of life, 422-W minimum after three years (CS), 409-W minimum after five years (CS2), 840-W minimum after seven years (CS3)

Spin-stabilized, approximately 90 rpm, $\pm 0.3/\pm 0.2$ -deg antenna pointing accuracy (CS, CS2/CS3)

Solid rocket motor for apogee maneuver, hydrazine propulsion for on-orbit use

Configuration

C-band: two 200-MHz (CS)/180-MHz (CS2, CS3) bandwidth single-conversion repeaters

K-band: six 200-MHz (CS)/130-MHz (CS2) bandwidth double-conversion repeaters, ten 100-MHz bandwidth single-conversion repeaters (CS3)

Capacity

C: 672 two-way voice circuits, or 432 voice circuits plus one TV program, or 192 voice circuits plus two TV programs per repeater (CS2, CS3)

K: 1920 two-way voice circuits per repeater (CS2, CS3)

Transmitter

C: 3820 and 4080 MHz

6-W TWT (CS, CS2)/7-W FET (CS3) per repeater, one spare (CS2, CS3)

29.5 dBW (CS, CS2)/31 dBW (CS3) minimum ERP per repeater

K: 17.7- to 21.2-GHz band (see communication subsystem figures for specific frequencies)

5-W (CS, CS2)/10-W (CS3) TWT per repeater, five spares (CS3)

37 dBW (CS, CS2)/38.7 dBW (CS3) (main islands), 33.4 dBW (CS3) (Okinawa) minimum ERP per repeater

Receiver

C: 6045 and 6305 MHz

Active plus spare receiver

Noise figure 9 dB (CS)/4 dB (CS2)/3.5 dB (CS3)

G/T -8 dB/K (CS), -6 dB/K (CS2), -4 dB/K (CS3)

K: 27.5- to 31.0-GHz band (see communication subsystem figures for specific frequencies)

Two active plus two spare receivers

Noise figure 13 dB (CS)/8 dB (CS2)/5 dB (CS3)

G/T -4.4 dB/K (CS), -3.8 dB/K (CS2), -0.7 dB/K (CS3) (main islands), -6.7 dB/K (CS3) (Okinawa)

Antenna

Despun horn and 45-deg contoured reflector, 37-in. dia. aperture, circular polarization

C: 25-dB minimum gain (main and outlying islands)

K: 33-dB minimum gain (main islands only) (CS, CS2, CS3), 27-dB gain (Okinawa) (CS3)

Design life

Three years (CS)/five years (CS2)/seven years (CS3)

Orbit

Synchronous equatorial, $\pm 0.1^\circ$ (CS, CS2)/ $\pm 0.05^\circ$ (CS3) E-W and N-S stationkeeping

Orbital history

CS: launched 15 December 1977, turned off and moved above synchronous orbit after CS2 launches

Delta 2914 launch vehicle

CS2A: launched 4 February 1983, turned off and moved above synchronous orbit after CS3 launches

CS2B: launched 5 August 1983, turned off and moved above synchronous orbit after CS3 launches

Japanese N-2 launch vehicle

CS3A: launched 19 February 1988, 132°E longitude

CS3B: launched 16 September 1988, 136°E longitude

Japanese H-1 launch vehicle

Management

Developed by Ford Aerospace and Communications Corporation under contract to Mitsubishi (Nippon Electric developed part of the CS communication subsystem and all of the CS2 and CS3 communication subsystems) for National Space Development Agency (NASDA) of Japan

Operated by NASDA (CS)/Telecommunication Satellite Corporation of Japan (CS2, CS3)

* * * * *

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Broadcasting Satellites (BSE, BS2, BS3)

In Japan, satellite television broadcasting [1-34] is used to:

- Extend current broadcasting to outlying areas and households on the main islands that have poor reception or none.
- Provide new broadcasting services.
- Promote technological developments.
- Provide an alternative to terrestrial equipment, which may be damaged by natural disasters.

The first satellite in the program was the Medium Scale Broadcasting Satellite for Experimental Purpose (BSE or BS). It was named *Yuri (Lily)* after launch. This satellite was used for many technical measurements; operational testing, especially with transportable terminals; and gaining experience in the control of a three-axis-stabilized satellite. The operational phase of the program uses the BS2 satellites, followed by the BS3 satellites.

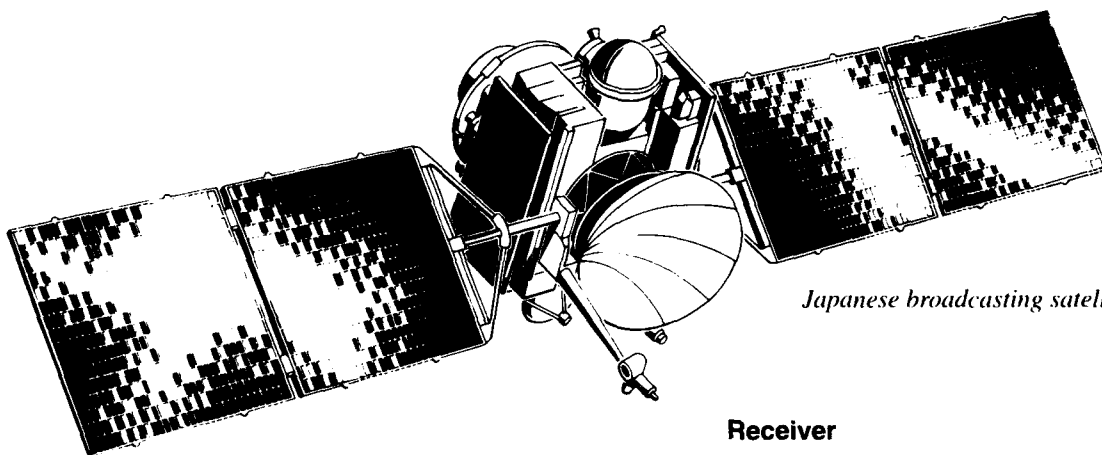
The BSE and BS2 satellites are very similar in design. Both are three-axis-stabilized with deployed solar arrays. All equipment is contained within or on the sides of the rectangular body.

The single large antenna is fixed to the satellite. The BS2 has improvements intended to increase its life to five years, compared to three years for BSE. Also, the BS2 satellites used a Japanese launch vehicle rather than the United States vehicle used for the BSE.

The communication subsystem is relatively simple and supports only two channels. The antenna pattern is shaped to provide coverage of both the main and outlying islands of Japan. There are two categories of difference between the BSE and BS2. One is adjustments in the frequencies, polarization, and some other parameters to conform to the decisions of the 1977 ITU space broadcasting conference. The other is changes as the result of improvements in electronics; these are noted on the figure. The following details apply to both satellites:

Satellite

Rectangular body, approximately 4 ft square, depth approximately 3 ft, overall depth (body, apogee motor nozzle, and



Japanese broadcasting satellite (BS2).

antenna) 10 ft (BSE)/9½ ft (BS2), overall span 29 ft 4 in. (BSE)/29 ft 2 in. (BS2)

780 lb in orbit, beginning of life

Sun-tracking solar array and NiCd batteries, 1000-W minimum at beginning of life (BSE), 780-W minimum after three years (BSE), 900-W minimum after five years (BS2)

Three-axis stabilization, ±0.2-deg (BSE)/±0.1-deg (BS2) pointing accuracy (3σ)

Solid rocket motor for apogee maneuver, monopropellant hydrazine for on-orbit use

Configuration

Two single-conversion channels, 50- and 80-MHz (BSE)/27-MHz (BS2) bandwidth

Capacity

One TV signal per channel

Transmitter

11.95 to 12.00 GHz and 12.05 to 12.13 GHz (BSE)

11.906 to 11.933 GHz and 11.983 to 12.010 GHz (BS2), ITU television broadcasting channels 11 and 15

Three transmitters (two on, one standby)

100-W output per channel

ERP per channel: 55-dBW minimum for primary area, 46-dBW minimum for fringe areas

Receiver

14.25 to 14.30 GHz and 14.35 to 14.43 GHz (BSE)

14.206 to 14.233 GHz and 14.283 to 14.310 GHz (BS2)

Two receivers (one on, one standby)

≤8.5-dB (BSE)/≤7.5-dB (BS2) noise figure

Antenna

Single parabolic reflector, 3.4 × 5.2 ft, 1.4- × 2-deg beamwidth (at -4 dB), 40.3-dB peak transmit gain, center-fed (BSE)/offset-fed (BS2); three feeds are used together to shape the beam (77% of the power goes through the main feed); linear (BSE)/circular (BS2) polarization

Design life

Three years (BSE)/five years (BS2)

Orbit

Synchronous equatorial, ±0.1°E-W and N-S stationkeeping

Orbital history

BSE: launched 7 April 1978, operations ceased June 1980 due to TWT failures, satellite life ended January 1982

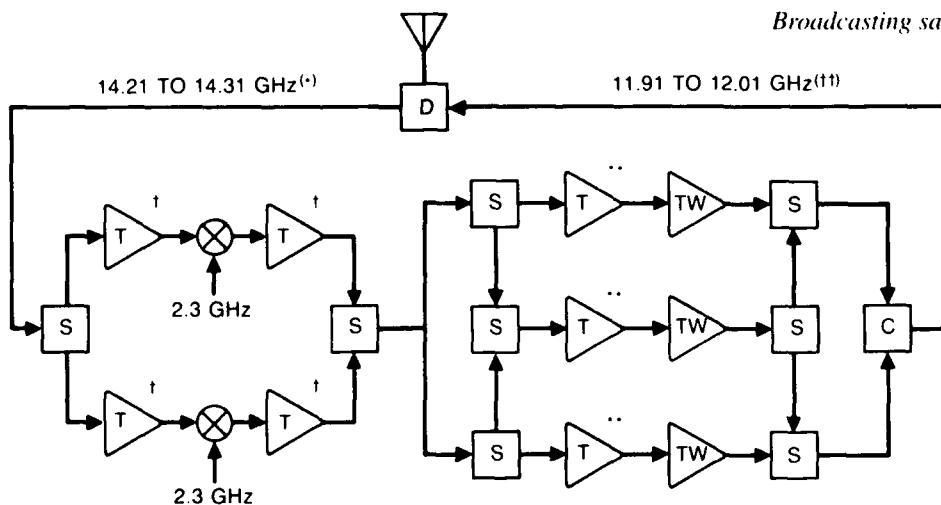
Delta 2914 launch vehicle

BS2A: launched 23 January 1984, early failures reduced status to experimental, moved above synchronous orbit, April 1989

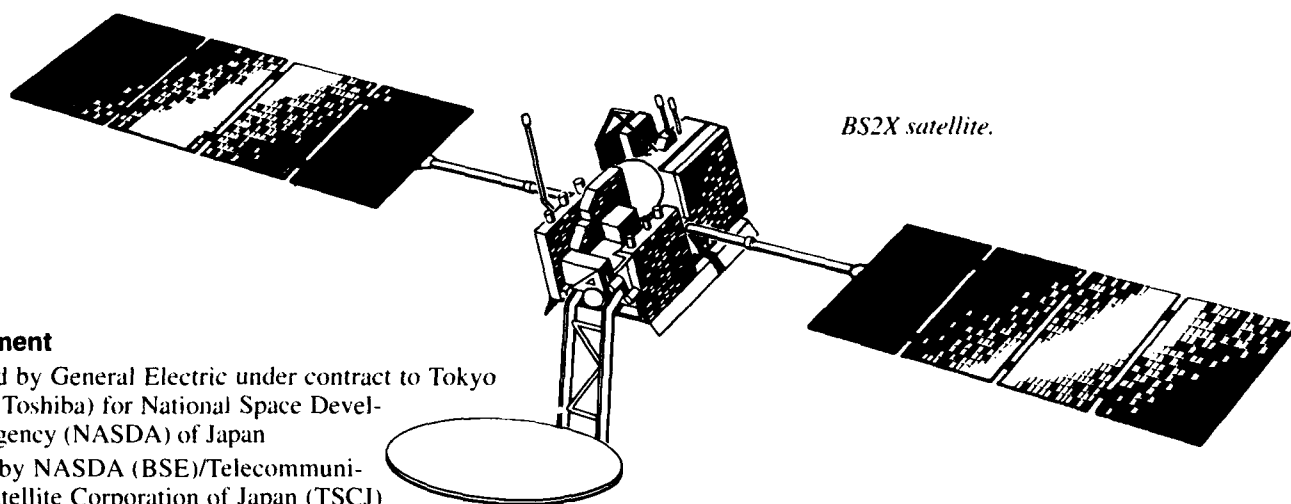
BS2B: launched 12 February 1986, 110°E longitude, backup satellite since beginning of BS3A use

Japanese N-2 launch vehicle

Broadcasting satellite communication subsystem (BS2).



* 14.25 to 14.43 in BSE
† TD in BSE
** TW in BSE
†† 11.95 to 12.13 in BSE



Management

Developed by General Electric under contract to Tokyo Shibaura (Toshiba) for National Space Development Agency (NASDA) of Japan

Operated by NASDA (BSE)/Telecommunications Satellite Corporation of Japan (TSCJ) (BS2)

The BSE was launched in April 1978. Television broadcasting ceased in June 1980 with the failure of the last TWTAs. Activities involving the satellite, that did not depend on the TWTAs, continued until January 1982, when the attitude control fuel was exhausted.

BS2A was launched early in 1984. Within three months, two of the three TWTAs had failed, reducing the satellite capacity to one channel. This upset the plans for operational broadcasting and caused a reassessment of Japanese practices in buying satellites. Considerable effort was devoted to identifying the problem and correcting it on BS2B. In 1985, BS2A had problems with attitude control and power and its status was reduced to experimental. The BS2B was launched in February 1986, a year later than planned because of the BS2A problems. In early summer, it experienced an attitude control problem, which was fixed by switching to the redundant controller.

Transmissions to the BSE and BS2s originate from either a fixed main terminal near Tokyo or transportable terminals. The former has a 26-ft antenna; the latter have 8-ft antennas for use in the main islands and 15-ft antennas for the remote islands. Home receiving antennas are as small as 2 ft in the main islands, and up to 8 ft in the remote islands.

In December 1986, two-channel operational broadcasting began. About 100,000 homes were equipped to receive the broadcasts. Twenty-four-hour broadcasting began in July 1987. By the beginning of 1989, 1.3 million homes were equipped to receive the broadcasts; a year later, the number was over 2 million. To reliably support this service, NHK, the national broadcasting company, required a backup satellite in orbit. Since BS2A had only one functioning TWTAs, it was not an adequate backup, so NHK ordered an interim satellite, which was designated BS2X. This satellite was intended to guarantee operations until the next regular generation, BS3A and BS3B, were available.

BS2X was originally built for the United States television broadcasting system of Satellite Television Corporation. When those plans were cancelled, the satellite became available for purchase. After the NHK purchase, the satellite required a different receiver, copied from other satellites, retuning of transmitter components, and changes in the antenna beam-forming network. Details of BS2X are:

Satellite

Rectangular body, 52 × 80 × 44 in., span of solar array 55 ft

Approximately 1400 lb in orbit, beginning of life

Sun-tracking solar arrays and NiCd batteries, approximately 2500 W at beginning of life, approximately 2000 W at end of life; batteries support only housekeeping functions during eclipse

Three-axis stabilization, ± 0.1 -deg accuracy, using a pivoted momentum wheel and magnetic torquers

Solid rocket motor for apogee maneuver, hydrazine propellant for on-orbit use

Configuration

Three 27-MHz bandwidth single-conversion transponders

Transmitter

In the 11.71- to 12.01-GHz band

One active plus one spare TWTAs per transponder, 230 W at beginning of life, 200 W at end of life

Receiver

In the 14.01- to 14.31-GHz band

One active plus two spare receivers

Antenna

One 85-in.-dia. parabolic reflector, multihorn feed to produce beam shaped to cover Japan, circular polarization

Design life

Seven years

Orbit

Synchronous equatorial, stationkeeping to $\pm 0.1^\circ$ N-S and E-W

Orbital history

Destroyed by launch vehicle explosion during ascent, 22 February 1990

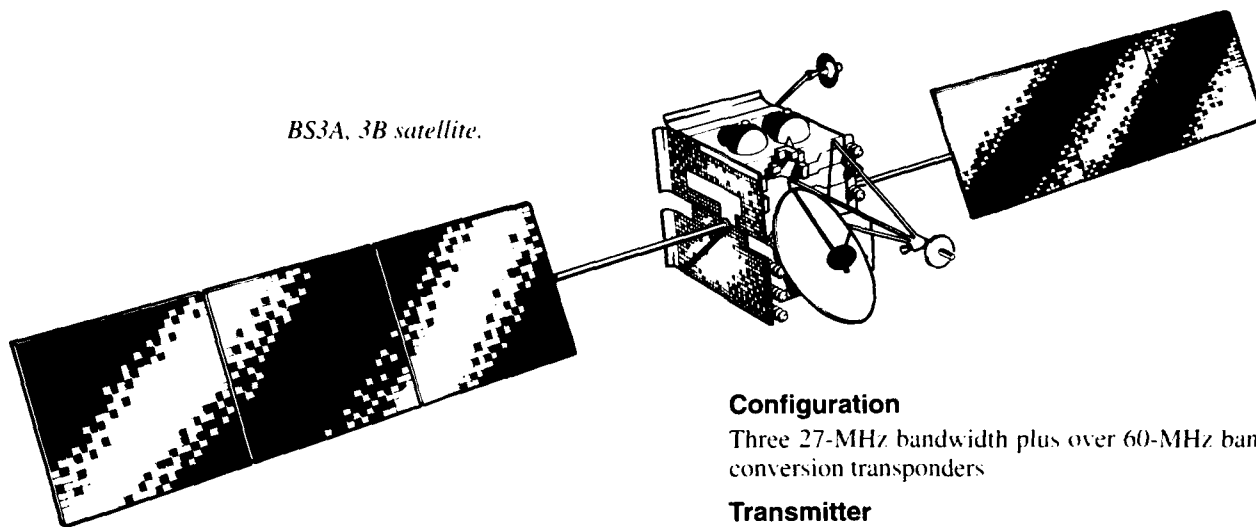
Ariane launch vehicle

Management

Developed for NHK by GE Astro Space

The destruction of BS2X forced NHK to depend on BS2B alone, since BS2A had reached the end of its useful life by early 1989. The next step was to wait for the two BS3 satellites. A contract for their development was awarded in fall 1985. The BS3 supports broadcasting of three channels and has a separate channel for experimental broadcasting of high-quality television. The satellite life, transmitter power, and some other performance

BS3A, 3B satellite.



characteristics are improved from the BS2 design. The satellite and broadcasting characteristics are:

Satellite

Rectangular body, $4.5 \times 5.8 \times 5.6$ ft. height including antennas 10.5 ft. span of solar arrays approximately 49 ft

Approximately 1300 lb in orbit, beginning of life

Sun-tracking solar array and NiCd batteries, approximately 1950 W at beginning of life, batteries support only housekeeping functions during eclipse

Three-axis-stabilized, using a pivoted momentum wheel and magnetic torquers, antenna pointing accuracy ± 0.1 deg

Solid rocket motor for apogee maneuver, monopropellant hydrazine for on-orbit use

Configuration

Three 27-MHz bandwidth plus over 60-MHz bandwidth single-conversion transponders

Transmitter

In the 11.75- to 12.01-GHz band (27-MHz transponders), and 12.61 to 12.67 GHz

One active plus one spare 120-W TWTA for each 27-MHz transponder, one 20-W TWTA for the 60-MHz transponder

ERP 55.5 dBW over Japanese main islands, 46.5 dBW minimum over outlying islands

Receiver

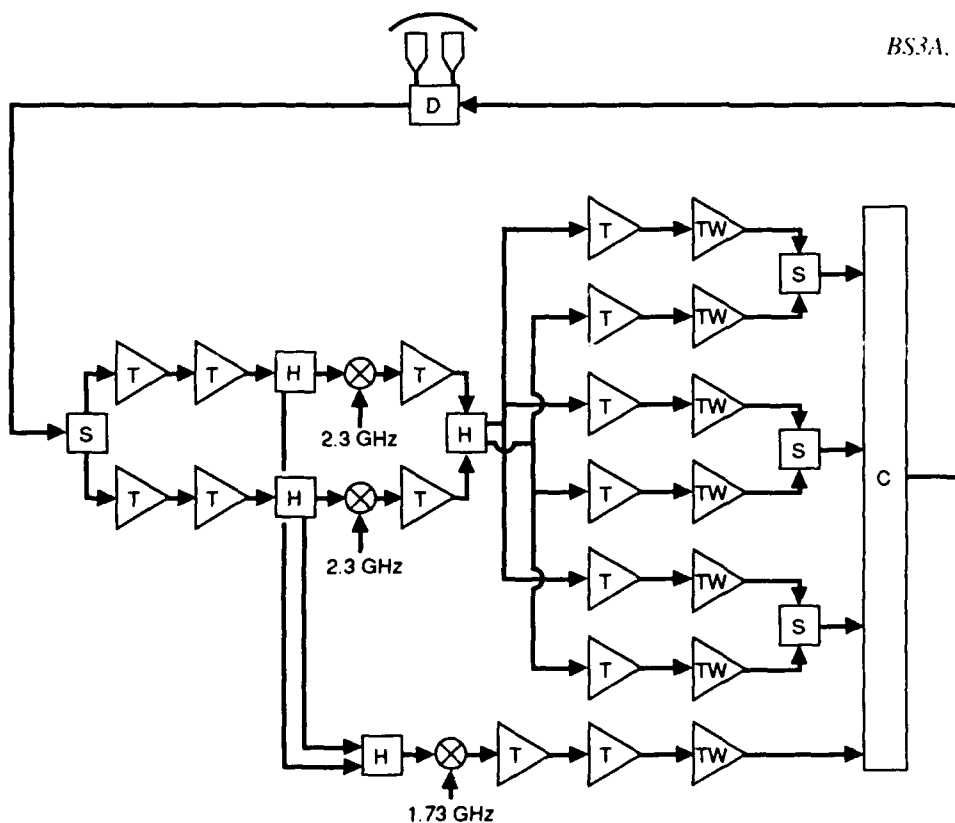
In the 14.05- to 14.31-GHz band (27-MHz transponders) and 14.34 to 14.4 GHz

One active and one spare receiver

Antenna

One offset-fed parabolic reflector 31 x 67 in., two feed horns, right-hand circular polarization

BS3A, 3B communication subsystem.



Design life

Seven years

Orbit

Synchronous equatorial, stationkeeping to $\pm 0.1^\circ$ N-S and E-W

Orbital history

BS3A launched 28 August 1990, in use, 110° E longitude

BS3B launched 25 August 1991

Japanese H-1 launch vehicle

Management

Developed for NASDA, acting for TCSJ and NHK, by NEC (communications payload and command and telemetry) and GE Astro Space (spacecraft)

Operated by TCSJ

The BS3A was launched in August 1990 and placed into synchronous orbit two days after launch. Initial tests revealed that the solar arrays were producing only 75% of their expected output power. This failure will allow operation of three broadcasting transponders in parts of the early years of life, but only two in later years as the solar array output drops. Therefore, BS3A will be assigned a backup role after November 1991, when BS3B completes checkout and begins operations.

Because of the continuing satellite problems, in 1990 the Japanese ordered another satellite, BS3H. This satellite was a copy of BS2X and was the second of two satellites built for Satellite Television Corporation but never used. It had the same communication subsystem modifications as BS2X. The BS3H was destroyed by an Atlas launch vehicle malfunction during ascent on 18 April 1991. This loss, coupled with further reduction of the solar array power on BS3A, will allow the transmission of only two channels until BS3B has passed through initial on-orbit (or "in-orbit") testing.

* * * * *

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2. R. Hayashi, Y. Furuhashi, and N. Fugono, "Propagation Characteristics for Millimeter and Quasi-Millimeter Waves by Using Three Japanese Geostationary Satellites," *Acta Astronautica*, Vol. 7, No. 11 (November 1980).
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25. Y. Nakamura, "The Operational Broadcasting Satellite System for Japan," Paper 35.4, *International Conference on Communications: ICC '84* (May 1984).
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JAPAN (Private Programs)

From its beginning, the space industry in Japan has been protected by government policy. This policy called for maximum development of Japanese industry and technology and maximum practical use of it in all launch vehicles and satellites. The entire space program was government-sponsored. Likewise, the telecommunication industry was protected, and all communications were provided by the government-owned Nippon Telephone and Telegraph (NTT).

By 1982, criticism of these policies emerged, primarily from Japanese businesses desiring new communication services. These services were not to be available on the CS2 satellites, and the users did not want to wait for the CS3 satellites. The years 1982 to 1984 were a period of debate in Japan, both in government and industry, between those who favored development of new services and those who favored a protected industry. There was also United States pressure for Japan to open their communications market to foreign suppliers, which would help to ease the balance of payments problem.

At the end of 1984, Japan enacted legislation containing major policy changes [1]. These changes became effective in April 1985. They included ending NTT's monopoly on providing communications, selling 50% of NTT to private investors in five years, permitting private firms to purchase and operate foreign satellites, and permitting up to one-third foreign ownership in companies providing domestic communications services. As a result of this legislation, three partnerships were formed to develop

and operate communications satellites, primarily to provide business communications and television broadcasting:

- Japan Communications Satellite, Inc., composed of C. Itoh, Mitsui, and Hughes Communications.
- Space Communications Corporation, composed of Mitsubishi Electric, Mitsubishi Trading, and Ford Aerospace.
- Satellite Japan Corporation, composed of Sony, Nissho-Iwai, Marubeni Trading, and RCA Astro Electronics.

The first two partnerships, JCSat and SCC, filed satellite applications with the government in early 1985. Both were approved in June 1985. The approvals included authorization to use the 12/14-GHz bands previously used in Japan only for terrestrial communications. The third partnership filed an application in mid-1985. This application was not approved by the government then, but a new application was approved in 1991. The first two systems have developed and launched satellites; the third hopes to launch a satellite by 1991.

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JCSat

Japan Communications Satellite (JCSat) [1-5], was the first of the two private systems to begin operating. It has two satellites in orbit, which were developed by the United States partner in JCSat. JCSat is operating as a wholesaler of communication services, leasing satellite capacity to other organizations in Japan.

The JCSat satellite is similar in many ways to SBS-6 and Intelsat VI. It is a large cylinder with an antenna and telescoping solar array that are deployed in orbit. The central portion of the upper solar array is a mirrored radiator for heat generated by the communication subsystem. This subsystem is mounted on a despun shelf directly behind the radiator. The shelf also supports the antenna, which is pointed using information derived from tracking a

ground-transmitted beacon. Further satellite details are as follows:

Satellite

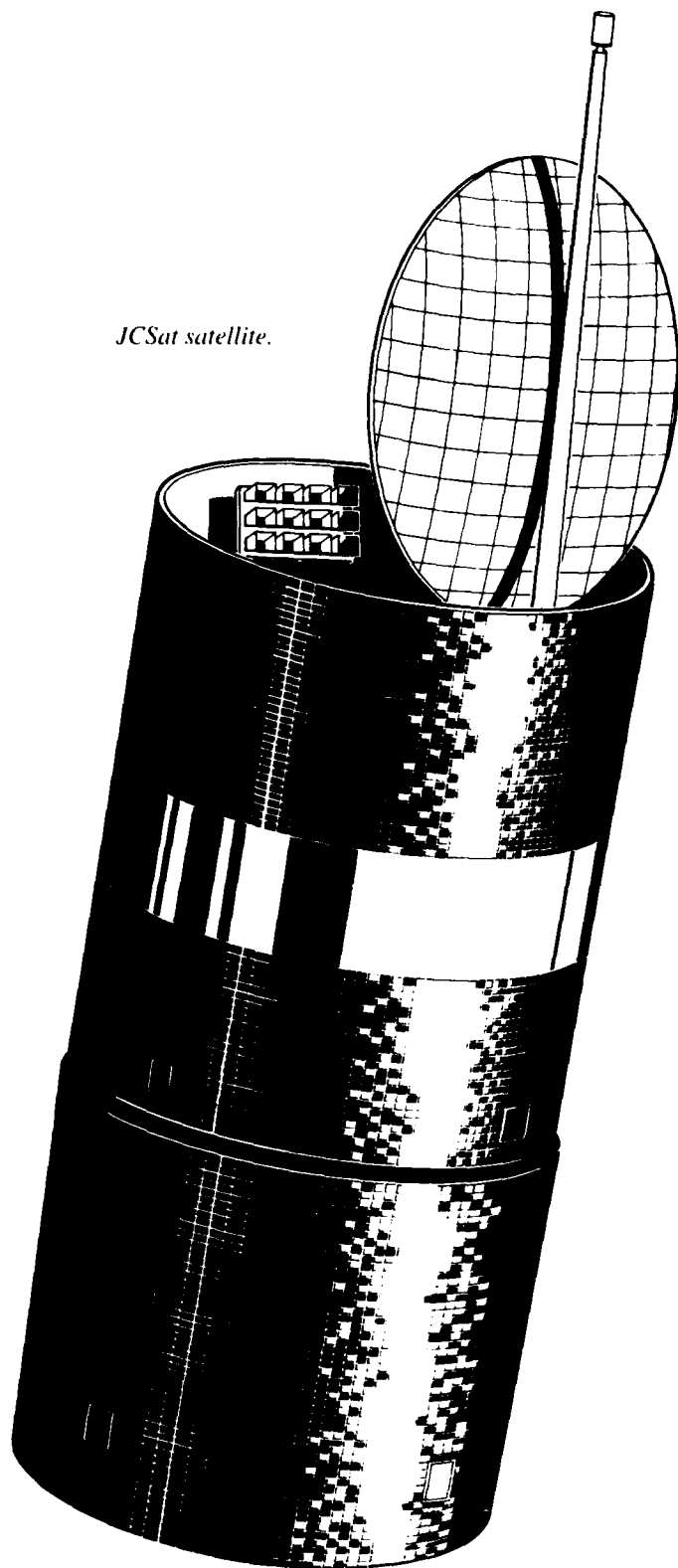
Cylinder, 12-ft dia., 11-ft 2-in. height stowed for launch, 33-ft height in orbit

3000 lb in orbit, beginning of life

Solar array and NiH₂ batteries, 2250 W at beginning of life, 1800 W minimum after ten years

Spin-stabilized, gyrostabilized, antenna pointing accuracy 0.05 deg by tracking an uplink beacon

JCSat satellite.



Unified bipropellant propulsion for perigee augmentation, apogee maneuver, and on-orbit use (solid perigee motor on JCSat 2)

Configuration

Thirty-two 27-MHz bandwidth single-conversion transponders, dual-polarization frequency reuse

Capacity

45 Mbps or one TV signal per transponder

Transmitter

12.25 to 12.75 GHz

One 20-W TWT per transponder plus eight spares per satellite

ERP 51 dBW over central Japan, 49 dBW over 80% of land area, 46 dBW over 95% of land area

Receiver

14.0 to 14.5 GHz

Four receivers (two active, two spare)

FET preamps, 3.0-dB noise figure

G/T 12 dB/K over central Japan, 10 dB/K over 90% of land area

Antennas

Dual-gridded offset-fed parabolic reflector, 7.9-ft dia., orthogonal linear polarizations; multihorn feed arrays, one per polarization, shape beam for four main Japanese islands plus Okinawa

Design life

Ten years

Orbit

Synchronous equatorial, stationkeeping to $\pm 0.05^\circ$ N-S and E-W

Orbital history

1: launched 7 March 1989, in use, 150° E longitude

2: launched 31 December 1989, in use, 154° E longitude

Ariane launch vehicle (1), Titan III (2)

Management

Developed by Hughes Aircraft Company for Japan Communications Satellites, Inc.

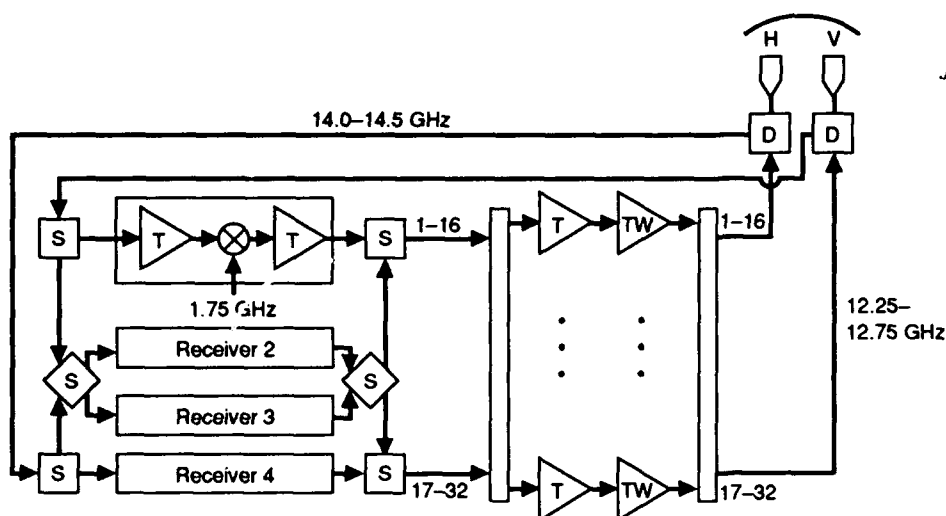
Operated by Japan Communications Satellite, Inc.

The JCSat contract required delivery in orbit of tested satellites. This required the manufacturer to make all arrangements for launch, transfer orbit control, and in-orbit testing. The two satellites were launched in March and December 1989; each began operational service about six weeks after launch. They are controlled from an operations center and ground station in Yokohama, with a backup station in Gunma.

Two-thirds of the transponders on the two satellites were in use by the fall of 1990. Uses include digital data transmissions, television distribution for network broadcasters and cable systems, transmission of live television news from remote locations, video conferencing, educational television for both high schools and businesses, and digital voice. Many users are connected to the operations center using voice circuits through the satellite; these provide good coordination and speedy action if problems occur. Ground antenna sizes vary between 4 ft and 36 ft. In a few years, the number of ground sites is expected to be about 10,000 with the smallest antennas, hundreds with medium-size antennas, and dozens with larger antennas.

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Superbird

Space Communications Corporation (SCC) obtained their satellites, named Superbirds [1-3], from their United States partner. They decided to use both the 20- and 30-GHz bands used by the government's communication satellites and the 12- and 14-GHz bands newly opened to satellite communications in Japan. The former have the advantages of wider bandwidth and minimal interference from terrestrial systems. The latter have the advantage of lower attenuation in the atmosphere. In both bands, maximum satellite performance is emphasized to minimize the required antenna size at ground terminals.

The satellite has a rectangular body housing all the equipment. The two large reflectors and the solar arrays deploy in orbit. One reflector is for 12/14-GHz transmission and reception, the other for 20/30 GHz. At each frequency, multiple feed horns generate a beam shaped to approximate Japanese geography, not including some outlying islands. One feed horn in the 20/30-GHz antenna also generates a spot beam for Tokyo. The spot beam covers 25% of the Japanese population.

The satellite has nineteen transponders in the 12/14-GHz bands. All are connected to the national coverage beams. The satellite has ten transponders in the 20/30-GHz bands. Seven are connected to the national coverage beams and three to the Tokyo spot beam. Two of the Tokyo transponders and two of the 20/30-GHz national beam transponders are interconnected on the satellite. This allows signals received on either beam to be transmitted on the other.

After the initial satellite contract, a modification was made to add a transponder in the 7- and 8-GHz bands used by military communication satellites of other nations. This transponder is for use by the Japanese Self-Defense Forces. Additional details about the SCC design are as follows:

Satellite

Rectangular body, 7.9 × 8.5 × 7.2 ft, span of deployed solar array 67 ft

Approximately 3080 lb in orbit, beginning of life

Sun-tracking solar arrays and NiH₂ batteries, approximately 4000 W

Three-axis stabilization, ±0.05-deg accuracy

Configuration

7/8 GHz: one 40-MHz bandwidth transponder

12/14 GHz: nineteen 36-MHz bandwidth, single-conversion transponders, dual-polarization frequency reuse

20/30 GHz: ten 100-MHz bandwidth transponders

Transmitter

7/8 GHz: in 7.25- to 7.75-GHz band

12/14-GHz: 12.35 to 12.75 GHz

One 35-W TWT per repeater plus four spares

ERP 53 dBW peak, 49 dBW edge of coverage

20/30 GHz: 17.775 to 18.115 and 18.495 to 19.315 GHz

One 20-W TWT per repeater plus six spares

ERP 54 dBW peak, 50 dBW edge of coverage (national beam), 60 dBW peak, 58 dBW edge of coverage (spot beam)

Receiver

7/8 GHz: in 7.9- to 8.4-GHz band

12/14 GHz: 14.0- to 14.4-GHz band, +9 dB/K G/T

20/30 GHz: 27.5- to 30-GHz band, +7 dB/K G/T (national beam), +17 dB/K G/T (spot beams)

Antennas

12/14 GHz: one offset-fed parabolic reflector with multiple feed horns to shape beam for Japan, dual linear polarizations

20/30 GHz: one 12-ft-dia. offset-fed parabolic reflector with four feedhorns to shape beam for Japan, one horn also used to provide one 0.3-deg spot beam, circular polarization

Design life

Ten years

Orbit

Synchronous equatorial, stationkeeping to $\pm 0.05^\circ$ N-S and E-W, 158 and 162°E longitude

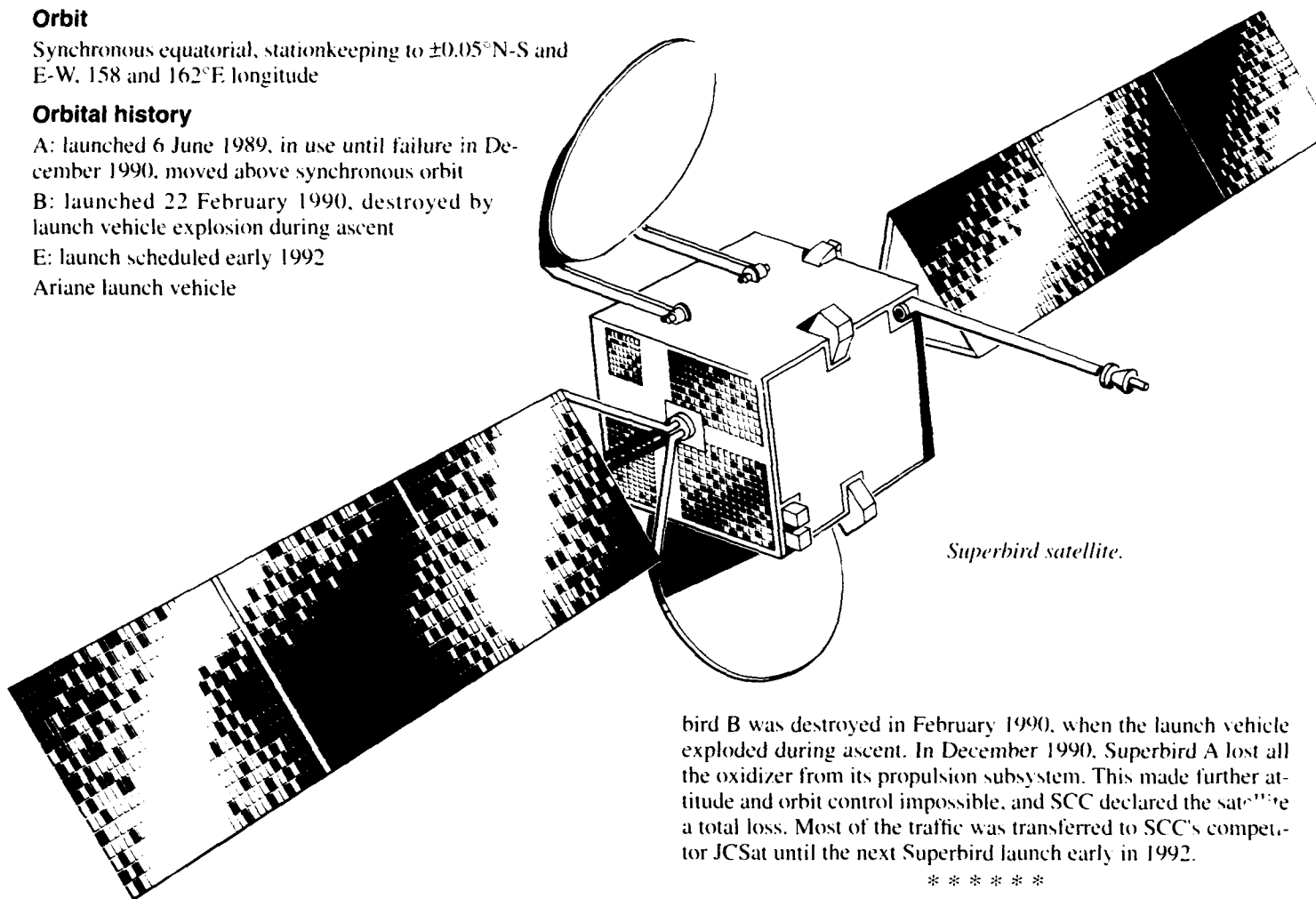
Orbital history

A: launched 6 June 1989, in use until failure in December 1990, moved above synchronous orbit

B: launched 22 February 1990, destroyed by launch vehicle explosion during ascent

E: launch scheduled early 1992

Ariane launch vehicle



Superbird satellite.

Management

Developed by Ford Aerospace and Communications Corporation (Space Systems Loral since 1990) for Space Communications Corporation

Operated by Space Communications Corporation

The first Superbird was launched in June 1989 and put into service a month later. The uses of the satellite included television distribution for networks and cable systems, transmission of television news from remote locations to studios, remote publishing, data transmissions, and television broadcasting to homes. Super-

bird B was destroyed in February 1990, when the launch vehicle exploded during ascent. In December 1990, Superbird A lost all the oxidizer from its propulsion subsystem. This made further attitude and orbit control impossible, and SCC declared the satellite a total loss. Most of the traffic was transferred to SCC's competitor JCSat until the next Superbird launch early in 1992.

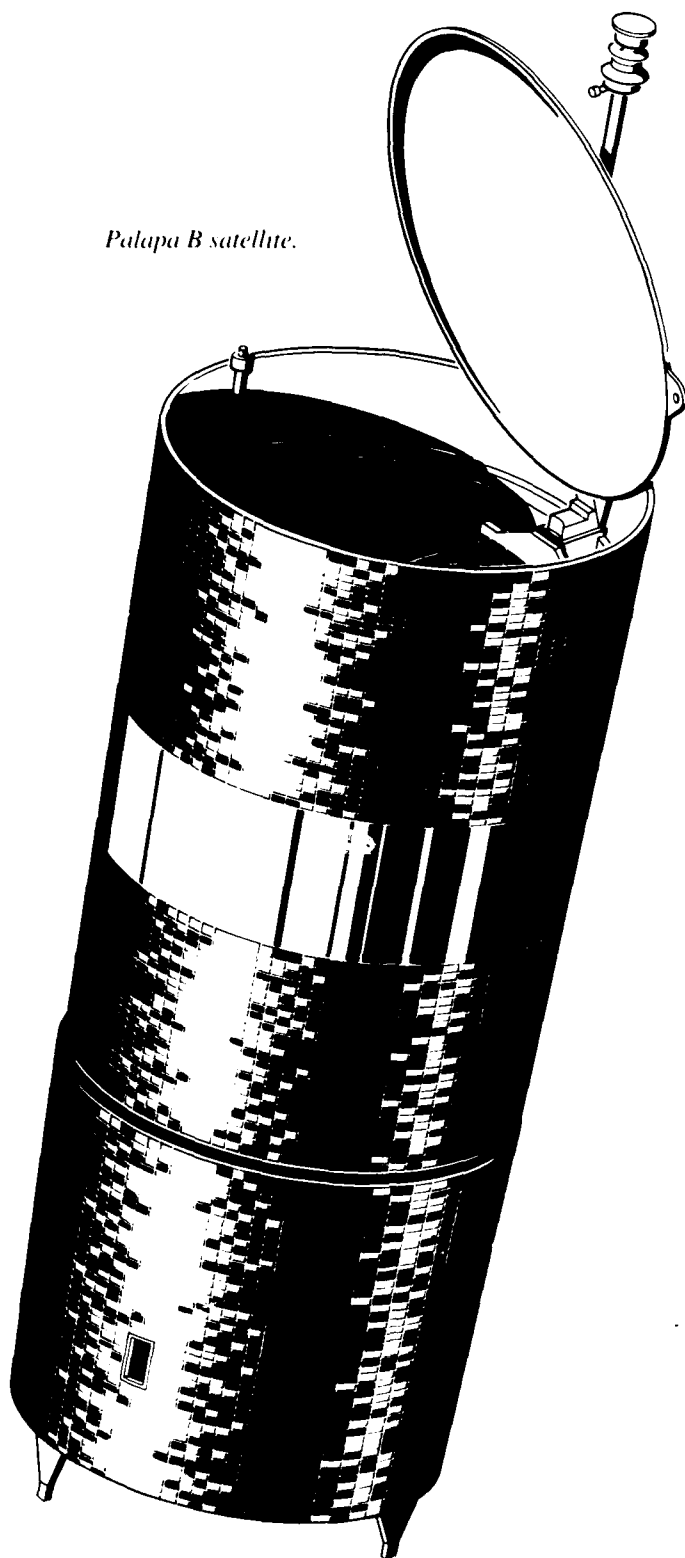
1. M. Ogata and M. Louie, "Optimization of Frequency Utilization for Communications Satellite Systems in Japan," Paper 86-0725, *AIAA 11th Communication Satellite Systems Conference* (March 1986).
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INDONESIA (PALAPA)

In Indonesia, the combination of geography, weather, and past economic conditions severely limited the development of communications facilities. In the mid-1970s, supported by greatly increased revenues from oil exports, the government began making significant improvements in communication facilities. A satellite communication system is one major part of the improvement program. The satellite system [1-11] is being used to open communication links to remote parts of the country, to improve communications between urban centers, for distribution of educational television, and for military communications.

The Indonesian satellites are named Palapa, a word signifying national unity. Two generations exist: the original Palapa satellites, now called Palapa A, and the newer Palapa B. The A satellites' design was like those of the Anik A and Westar I to III satellites. The B satellite was one version of a design used for a large number of satellite programs, including SBS, Anik C and D, and Galaxy. The Palapa satellites support the services just mentioned within Indonesia and provide capacity for lease to neighboring nations. These nations are Singapore, Malaysia, Thailand, and the Philippines, which, along with Indonesia, comprise the

Palapa B satellite.



the lower solar array and the antenna are deployed in orbit. The internal arrangement of both satellites is shown. The satellite details are as follows:

Satellite

A: cylinder, 75-in. dia., overall height 139 in.

B: cylinder, 85-in. dia., 112-in. height in launch condition; 274-in. (22 ft 10 in.) height deployed

670 lb (A)/1435 lb (B) in orbit, beginning of life

Solar cells and NiCd batteries, 300 W (A)/1060 W (B) beginning of life, approximately 240 W (A)/approximately 830 W (B) end of life

Spin-stabilized, approximately 90 rpm (A)/50 rpm (B), gyrostat (B), antenna pointing to ± 0.1 deg (A)/ ± 0.05 deg (B) or better

Solid rocket motor for apogee maneuver, monopropellant hydrazine for on-orbit use

Configuration

A: twelve 36-MHz bandwidth single-conversion repeaters

B: twenty-four 36-MHz bandwidth single-conversion repeaters, dual-polarization frequency reuse

Capacity

A: 600 two-way voice circuits or one TV signal per repeater

B: somewhat greater than A, depends on evolution of ground terminals and access techniques

Transmitter

3702 to 4178 MHz (A), 3702 to 4198 MHz (B)

One 5-W (A)/10-W (B) TWT per repeater, no spares (A), one spare per four repeaters (B)

ERP: 32 dBW (A)/34 dBW (B) per repeater over Indonesia, 27 dBW (A)/32 dBW (B) per repeater over neighboring nations

Receiver

5927 to 6403 MHz (A), 5927 to 6423 MHz (B)

One (A)/two (B) active and one (A)/two (B) spare receivers

G/T: -7 dBW/K (A)/-5 dB/K (B) over Indonesia

Antenna

One 60-in. (A)/72-in. (B) dia. offset-fed parabolic reflector, multiple feeds shape beam to optimize coverage of Indonesia and neighboring nations, linear polarization (A), dual linear polarizations (B)

Design life

Seven (A)/eight (B) years

Orbit

Synchronous equatorial, stationkeeping to $\pm 0.1^\circ$ N-S and E-W

Orbital history

A1: launched 8 July 1976, no longer in use, moved above synchronous orbit

A2: launched 10 March 1977, no longer in use, moved above synchronous orbit

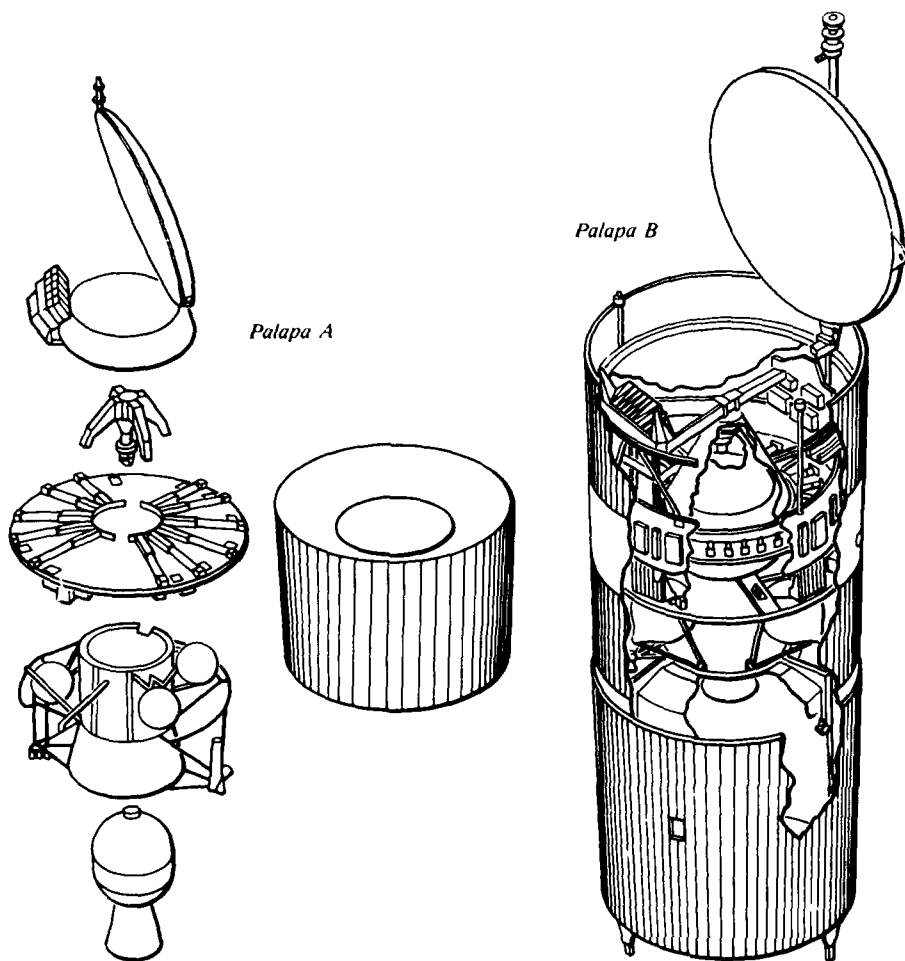
Delta 2914 launch vehicle

B1: launched 18 June 1983 (deployed from Shuttle, 18 June), 118° E longitude, in use

B2: launched 3 February 1984 (deployed from Shuttle 6 February), PAM failure left satellite in low orbit, returned to earth November 1984

Association of Southeast Asian Nations (ASEAN). The Palapa A coverage is shown compared with the geography of these nations. Palapa B has about 2 dB improved performance in general, in addition to better shaping of the transmit pattern for Thailand and the northern Philippines.

The two Palapa satellite designs are spin-stabilized. On Palapa A, the antenna was despun, and all other equipment was mounted within the spinning satellite body. On Palapa B, the entire communication subsystem is mounted on a despun platform, whereas support subsystems are still attached to the spinning body. Also,



Palapa A and B satellite details.

Shuttle/PAM-D launch vehicle

B2P: launched 20 March 1987, 113°E longitude, in use

B2R: launched 13 April 1990, 108°E longitude, in use

B4: launch scheduled early 1992

Delta/PAM-D launch vehicle

Management

Developed by Hughes Aircraft Company for Perumtel (Perusahaan Umum Telekomunikasi), the Indonesian Government communications agency

Operated by Perumtel

The Palapa A communication subsystem had twelve channels. Redundant wideband receivers were followed by twelve nonredundant channelized transmitters. The Palapa B communication subsystem has twenty-four channels. The equipment is basically double that of Palapa A, with each set of twelve channels received and transmitted on separate polarizations. Also, some transmitter redundancy is provided, and the transmitter output power has been doubled.

The Palapa A satellites were launched in 1976 and 1977. They remained useful until 1985 and 1986, two years beyond their design lifetime. The first Palapa B was launched in June 1983 and took some traffic from the A satellites, in addition to supporting new services. The second B satellite was launched in February 1984 but was left in a low orbit by a malfunction of the perigee

motor. The same fate happened to Westar VI, and a rescue plan was devised for the two satellites [2]. Numerous adjustments to the satellite orbit were made while rescue equipment was being prepared. A Shuttle rendezvoused with the satellite in November 1984, and two astronauts captured the satellite and secured it in the Shuttle. It was returned to earth and offered for sale by the insurance companies. It was purchased in 1986 for refurbishment and resale to Indonesia. The manufacturer refurbished the satellite by replacing components that were used during the orbit adjustments prior to the rescue. These components included the apogee motor, the batteries, and the attitude control thrusters. The satellite was renamed Palapa B2R (R for refurbished) and relaunched in 1990.

To provide a backup to Palapa B1, construction of a third satellite was started in 1984, when Palapa B2 was in low orbit waiting for the rescue attempt. This satellite was originally Palapa B3, but its name became Palapa B2P. It was launched in 1987. Both Palapa B2P and B2R are in use. Because of continually increasing traffic, Palapa B4 is being built and will be launched in 1992. The projected operating lives of Palapa B2P and B2R indicate that another satellite launch is desirable in 1995. That will probably be the first of the Palapa C series, which might be a multifunction satellite, similar in concept to India's Insat.

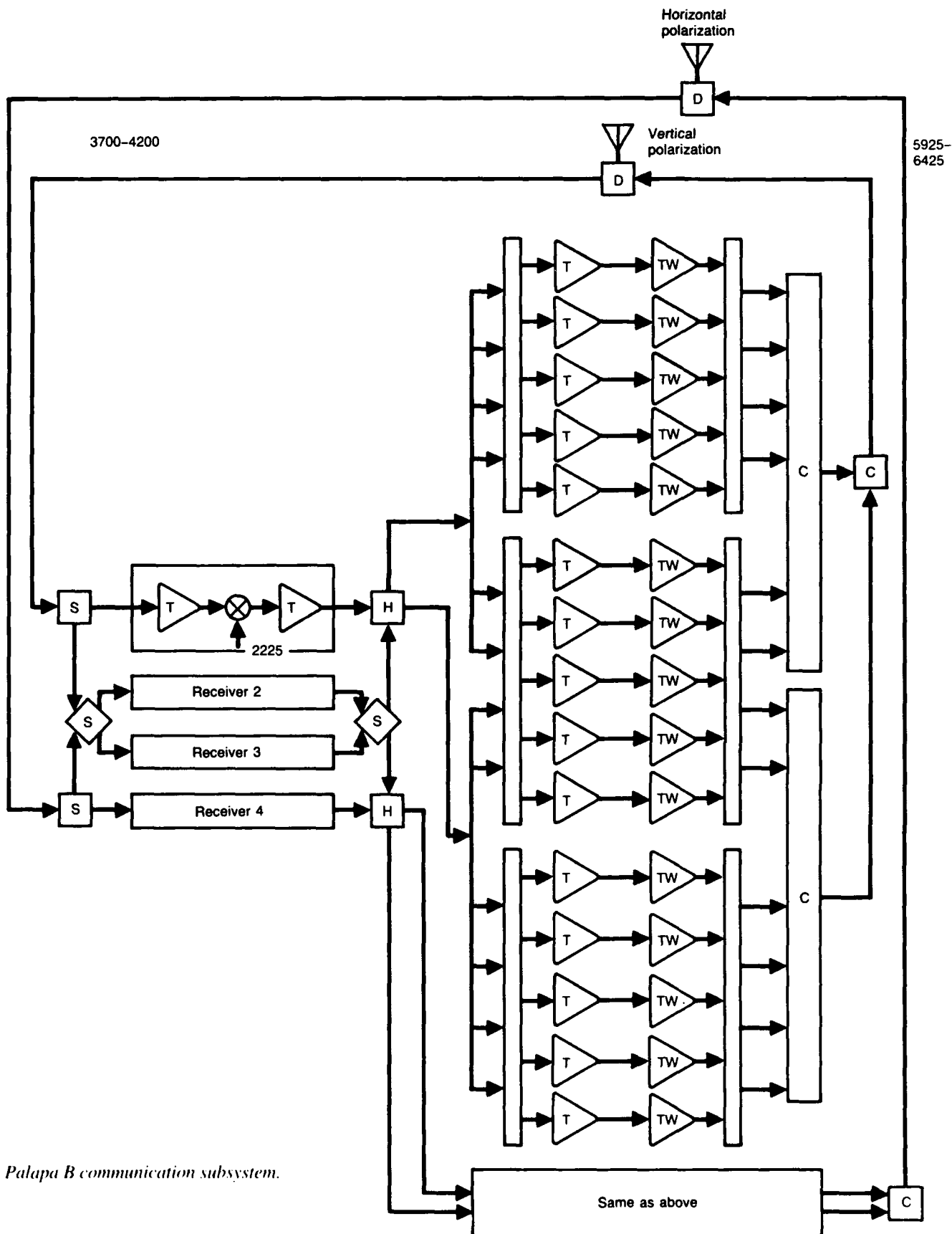
Additional missions could include weather

photography, VHF communications for coastal ships, or television broadcasting. No firm plans have been announced for Palapa C.

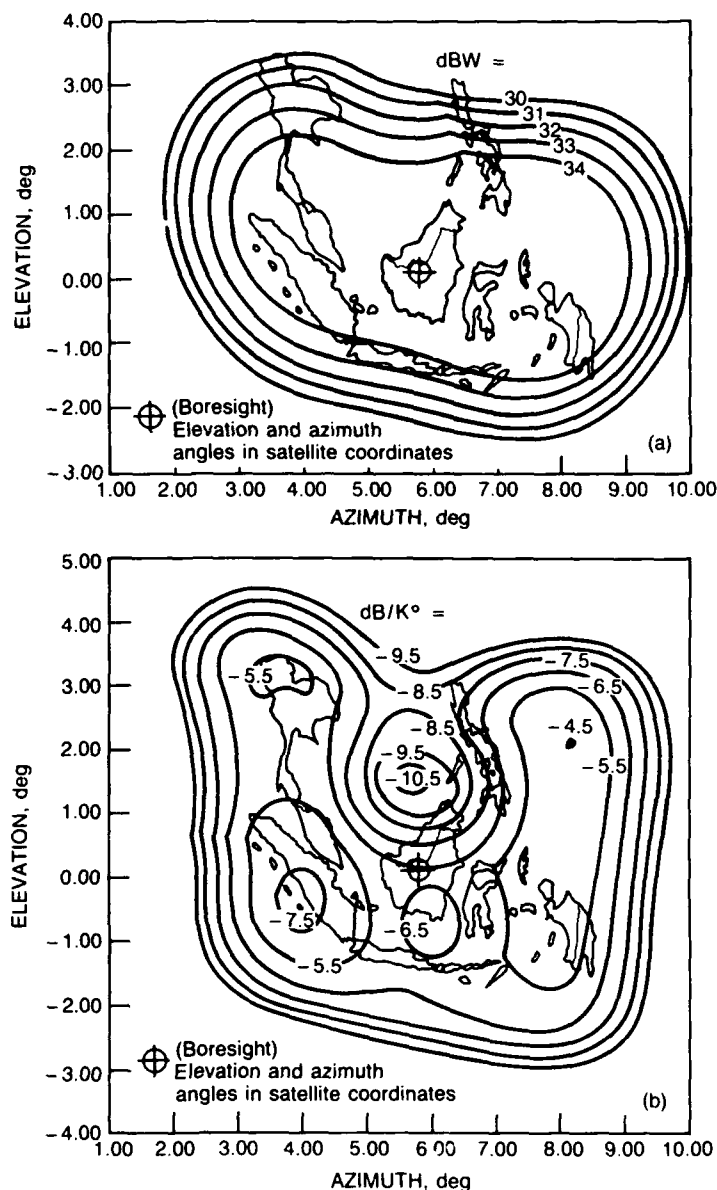
The Palapa system began operations in August 1976 on the date of the thirty-first anniversary of Indonesian independence. Forty ground terminals were in use then, with ten more added in 1978. By 1981, the number of terminals had increased to 120, with the total expected to increase to about 300 in the coming years. Transmission techniques include FDM/FM trunk telephone links, SCPC thin route telephony and telegraphy, and FM television. The SCPC links are split between preassignment and demand assignment. TDMA equipment was installed in some terminals in the 1980s, and an improved demand assignment controller replaced the original one about 1990. Also, a low-rate digital packet transmission network is in development, and the use of video conferencing is being studied. The Philippines, Thailand, and Malaysia are all using leased capacity for their internal communications. Singapore uses Palapa for communications with these neighboring nations.

* * * * *

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Palapa antenna pattern. (a) transmitter ERP (per channel); (b) receiver G/T.

INDIA

From July 1975 through July 1976, India used the ATS 6 satellite for experimental television broadcasting. At the beginning of the 1970s, as this experiment was being planned, India had the intention of immediately following it with a national communication and broadcasting satellite [1-8]. This intention was supported by studies in the United States and India. Furthermore, India had the desire to develop its own technical capabilities to the extent that it could design and develop its own satellites for use in the 1980s. All of these plans slowed considerably, and no Indian satellite was available after the ATS experiment. Instead, additional experiments were conducted from 1977 to 1979 using one of the Symphonie satellites that had been moved to 49°E longitude. This activity was called the Satellite Telecommunications Experimental Project (STEP), the purpose of which was to collect data for further development of India's ground terminal facilities. Afterwards, India continued its interim measures with a quarter transponder lease from Intelsat beginning in 1979. This satellite capacity is used by India's two Intelsat terminals and several

smaller terminals. Together with the Intelsat lease, India continued to gain experience with the APPLE (Ariane Passenger Payload Experiment) satellite. Culminating all the preparatory efforts, Insat, India's national satellite system, started operating in 1982.

* * * * *

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1979), p. 72; (29 June 1981), p. 18; (6 July 1981), p. 20; (10 August 1981), p. 53; (24 August 1981), p. 62; (5 April 1982), p. 56; (19 April 1982), p. 24; (26 April 1982), p. 27; (22 November 1982), p. 80; (25 April 1983), p. 21; (13 June 1983), p. 29; (19 September 1983), p. 14; (2 December 1985), p. 20; (24 March 1986), p. 83; (4 August 1986), p. 29.

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APPLE

The APPLE satellite [1-6] was proposed by India in 1975, in response to an ESA offer to provide free launches on Ariane development flights. The proposal was accepted in 1976 and work began in 1977. India's objectives with APPLE were to

- Gain experience in mission planning and satellite operations.
- Build a three-axis-stabilized satellite.
- Develop and use a communications payload.

The APPLE program was managed by the Indian Space Research Organization (ISRO), which is a part of the national government's Department of Space.

ISRO designed the APPLE satellite and assembled it, using items manufactured by ISRO and by contractors in India, France, Germany, and the United States. The satellite was a cylindrical structure with two internal equipment shelves and two solar panels. The payload was a single, redundant, communications transponder that used the antenna mounted on the front end of the cylinder. Additional satellite details are as follows:

Satellite

Cylinder, 47-in. dia., 47-in. height; height including antenna 6½ ft, span of deployed solar arrays 15 ft

836 lb in orbit, beginning of life

Sun-tracking solar array and NiCd batteries, 280 W beginning of life, 210 W end of life (failure of one panel to deploy reduced these values by 50%)

Three-axis stabilization using redundant momentum wheels and magnetic torquers, 0.25-deg accuracy in pitch and roll, 0.4 deg in yaw

Solid rocket motor for apogee maneuver, hydrazine for on-orbit use

Configuration

Two repeaters (one active, one spare)

Transmitter

4140 to 4180 MHz

One TWT per repeater, approximately 5-W output
ERP on axis 31.5 dBW

Receiver

Approximately 6 GHz, FET preamplifier

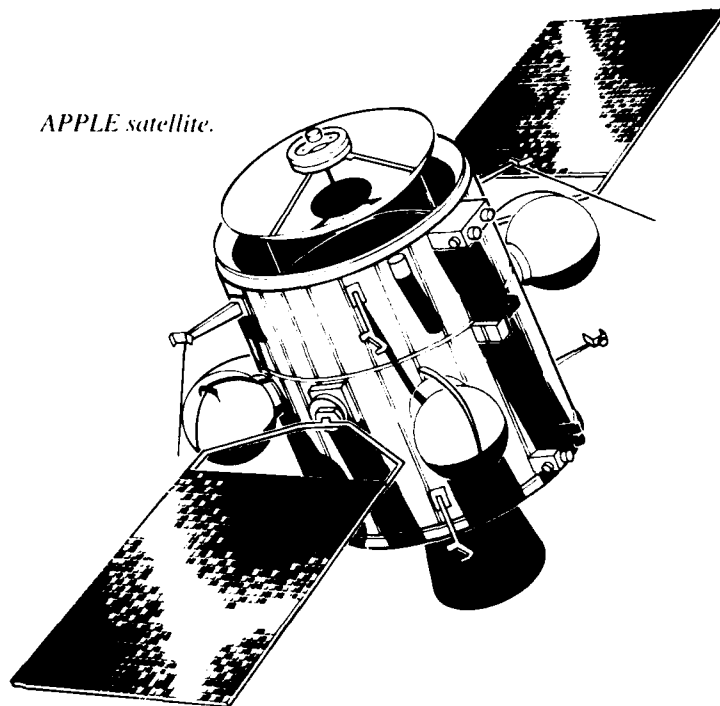
Antenna

One 35-in.-dia. parabola with prime focus feed

Design life

Two years

APPLE satellite.



Orbit

Synchronous equatorial, stationkeeping to $\pm 0.1^\circ$ N-S and E-W

Orbital history

Launched 19 June 1981, in use until turned off September 1983, moved out of synchronous orbit

Management

Developed by ISRO

Operated by ISRO

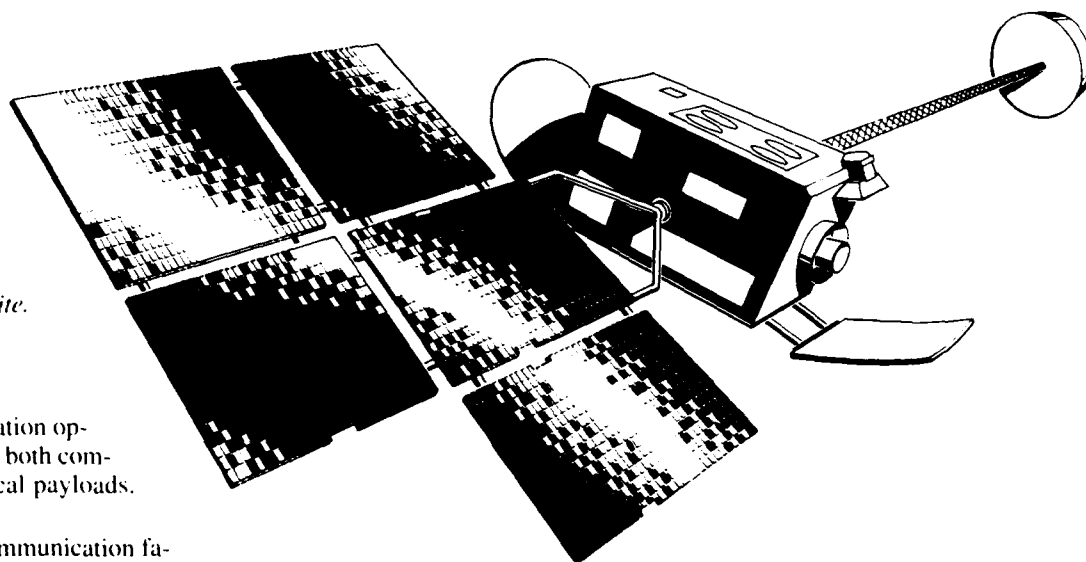
APPLE was launched in June 1981. ISRO took control of it beginning with the transfer orbit. After injection into synchronous orbit, one of the solar panels could not be deployed. This cut the available power by one half and also caused thermal problems. Nevertheless, techniques were developed that allowed use of the satellite throughout its two-year design life. A wide variety of experiments was conducted with APPLE, including 30-Mbps TDMA for telephone, spread spectrum multiple access, random access packet networks for computer communications, and television and facsimile transmission. APPLE was turned off in September 1983.

* * * * *

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Insat I

Insat satellite.



Insat I is India's first-generation operational satellite [1-12]. It has both communications and meteorological payloads. It is used to:

- Supplement terrestrial communication facilities on major interurban links.
- Provide reliable communications to areas isolated by difficult terrain.
- Provide television broadcasting to rural areas for educational and agricultural programs.
- Collect satellite imaging and terrestrial data for weather forecasting.

The first two objectives are accomplished with a twelve-transponder payload that uses the 4- and 6-GHz frequency bands. Its design, with redundant wideband receivers and channelized transmitters, is relatively simple. The only unusual feature is the interconnection with other payloads. The broadcasting payload satisfies the third objective. It has two transponders that have 6-GHz uplinks and 2.5-GHz downlinks. Both share antennas with the communications payload.

The weather forecasting objective requires two payloads. One is a visible light and infrared radiometer on the satellite, which transmits images of the earth. Resolution is 2.75 km in visible light and 11 km in infrared. One complete image, covering a 20-deg square field at the satellite, is collected and transmitted in 23 min. After 7 min, another image is started. The data relay payload receives brief transmissions from many data collection platforms at about 400 MHz and retransmits them to a central site at about 4 GHz. The platforms are both on land and ocean and collect meteorological and hydrological data. Both the radiometer and data relay downlinks use the antennas of the other payloads.

The satellite details are as follows:

Satellite

Rectangular body, $5.1 \times 4.7 \times 7.2$ ft. N-S span of deployed solar array and solar sail 64 ft. E-W span of deployed antennas 19 ft. Approximately 1230 to 1400 lb in orbit, beginning of life. Solar cells and NiCd batteries, approximately 1200 W beginning of life, 900 W minimum after seven years, eclipse power for housekeeping. DR, RA, and only four COM transponders. Three-axis stabilization, two momentum wheels and one reaction wheel plus magnetic torquers, antenna pointing accuracy ± 0.2 deg (pitch and roll), ± 0.4 deg (yaw). Unified bipropellant propulsion for apogee maneuver and on-orbit use.

Configuration

Communications (COM): twelve 36-MHz bandwidth single-conversion transponders

Broadcasting (BR): two 36-MHz bandwidth single-conversion transponders

Data relay (DR): one 200-kHz bandwidth transponder

Radiometer (RA): 400 kbps transmission of data from onboard radiometer

Capacity

COM: approximately 8000 two-way voice circuits plus one TV program

BR: two TV programs

Transmitter

COM: 3712 to 4028 MHz and 4042 to 4198 MHz

One 4.5-W TWT per repeater, 32 dBW minimum ERP per repeater over primary coverage area at end of life (primary coverage, about 80% of India; secondary coverage, some peripheral parts of India plus off-shore islands), one spare TWT per two repeaters on Satellite 1D

BR: 2557 to 2633 MHz

One 50-W TWT per repeater plus one spare, 42 dBW minimum ERP per repeater over primary coverage area at end of life (primary coverage, about 80% of India; secondary coverage, some peripheral parts of India plus off-shore islands)

DR: 4038.1 \pm 0.1 MHz, 19 dBW minimum ERP at end of life

RA: 4034.55 MHz, 8.5 dBW minimum ERP at end of life

Receiver

COM: 5937 to 6253 MHz and 6267 to 6423 MHz

Two receivers (one on, one spare)

G/T -6 dB/K minimum, -4.2 dB/K typical

Two receivers (one on, one spare)

BR: 5857 to 5933 MHz

Two receivers (one on, one spare)

G/T set by and same as communications receiver

DR: 402.75 \pm 0.1 MHz

Two receivers (one on, one spare)

G/T -19 dB/K

Antenna

COM and BR: one 54-in. dia. offset-fed parabola for all reception and COM odd channels transmission, linear polarization, 4.5-deg beamwidth; one 60- \times 63-in. offset-fed parabola for COM even channels (linear polarization) and BR transmission (LHCP), 4.5-deg beamwidth; each has four feed horns

DR: array of four annular slot antennas, RHCP, 38-deg beamwidth for receive; communications antenna for transmit

RA: communications antenna

Design life

Seven years

Orbit

Synchronous equatorial, stationkeeping to \pm 0.1°N-S and E-W

Orbital history

IA: launched 10 April 1982, died 4 September 1982, moved above synchronous orbit

Delta 3910/PAM launch vehicle

IB: launched 30 August 1983, 74°E longitude, in use

Shuttle/PAM launch vehicle

IC: launched 21 July 1988, 56°E longitude, power failure allows use of about half of the satellite

Ariane launch vehicle

ID: launched 12 June 1990, 83°E longitude, in use

Delta 4925 launch vehicle

Management

Developed by Ford Aerospace and Communications Corporation (Space Systems Loral since 1990) for Indian Department of Space

Operated by Department of Space

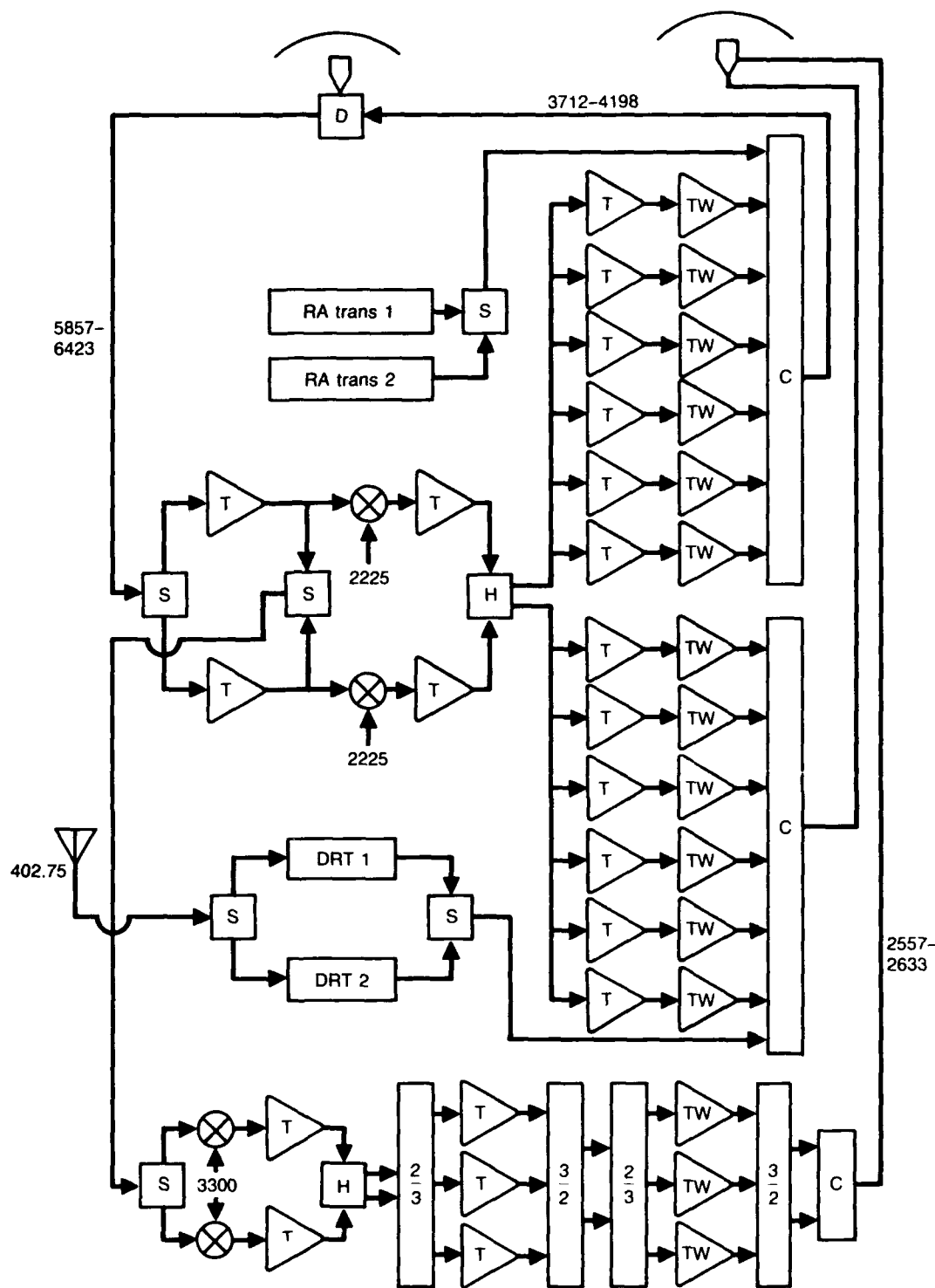
The Insat communications payload is used primarily for telephony. Typically, one transponder is used for television program distribution. Large and medium-size terminals use FDM/FM/FDMA transmissions for multichannel links. Small terminals, handling fewer circuits, use SCPC/FDMA. The broadcast payload accommodates one television program and several voice circuits per transponder. All can be received by community terminals with 12-ft-diameter antennas constructed of wire mesh. The voice circuits are radio broadcasts and a disaster warning channel. The transmission rate for the radiometer data is 400 kbps; the data collection platforms transmit at 4.8 kbps. Both use PSK.

The antennas deployed from opposite sides of the body handle all receiving and transmitting functions except for uplinks from the data collection platforms. The feed horns for the rectangular reflector are on the edge opposite its deployment hinge. The circular items between them are the launch vehicle adapter and apogee motor nozzle. Data collection uplinks are received through the UHF antenna, which is the four rings on the earth-viewing face of the satellite. The solar array is only on one side of the satellite rather than consisting of two equal wings as on other three-axis-stabilized satellites. This is required so that the radiative cooler for the radiometer's infrared detectors, which is on the side opposite the solar array, has a clear view to deep space. The object on that same side of the satellite is a solar sail. The sail, by the geometry of its design and its separation from the satellite on a 30-ft deployable boom, will not interfere with the radiative cooler. The function of the sail is to counteract the torque caused by solar radiation pressure on the array.

All equipment is mounted within the satellite body. The apogee motor and in-orbit propulsion are combined in one bipropellant system. In-orbit thruster firings and rotation of the sun-tracking solar array are accomplished during the 7-min periods when the radiometer is not active. During the 23-min imaging cycle, they are inhibited to improve attitude stability.

Insat 1A was launched in April 1982. After it reached geosynchronous orbit, one antenna deployed only after many attempts, and the sail never deployed. During a September 1982 attitude maneuver, the torque caused by the solar sail not being deployed resulted in the moon being in the field of view of the active earth sensor. The unpredicted moon interference caused the satellite attitude reference to be lost. Because the satellite command receiver was connected to the narrow coverage communications antenna rather than an omni antenna, the command link was broken as the satellite attitude changed. As a result, safing commands could not be received, all fuel was consumed, and the satellite was lost. Between that time and October 1983, when Insat 1B became operational, communications services were maintained using leased Intelsat transponders and a leased transponder on a Soviet Stationar satellite.

Insat 1B, with modifications to avoid the previous problems, was launched in August 1983. After initial problems with solar array deployment, it began orbital testing with all equipment acceptable. After testing, it entered operational service and has worked without significant problems. A few months earlier, a contract was signed for production of Insat 1C, which was



Insat communication subsystem.

DRT Data relay transponder
RA Radiometer

launched in 1988. In 1985, a contract was signed for Insat ID, which was launched in 1990.

During or soon after deployment in synchronous orbit, Insat IC suffered a failure in its power subsystem. This failure terminated use of half of the communications transponders and half of the broadcasting transponders. The other half of the transponders plus the data relay and radiometer payloads have operated successfully.

Insat ID was attached to its launch vehicle in June 1989, when a crane hook fell on it and damaged it. It was returned to the manufacturer for repairs and while there suffered slight additional damage in the October 1989 San Francisco earthquake. It was repaired and launched in 1990, one year after the accident. It has operated properly since launch.

Thirty-eight ground terminals are in operation with Insat for telephony. More terminals will be added to the network, which

supplements terrestrial facilities on main routes and provides new links to rural areas. Antenna diameters vary from 15 to 36 ft, depending on required capacity. About 4000 community terminals receive television broadcasts from Insat. About 200 of these terminals are connected to conventional television transmitters, which rebroadcast the signal in the local area. The use of Insat increases the portion of India's population, to which television is available, from 25% to 70%. Over 100 data collection platforms and 200 disaster warning receivers also have been installed for use with Insat. A governmental data network was established in 1987 with over 400 terminals.

* * * * *

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Insat II

Insat II [1-2] is an Indian-built series of satellites which will replace the Insat I series. Insat II has the same payloads, for communications, broadcasting, data relay, and imaging, plus an additional payload for search and rescue. The satellite design was chosen after a study of large and medium-size multipurpose satellites and multiple medium-size satellites with single or dual payloads. Insat II is the medium-size multipurpose option.

The communications and broadcasting payload requirements were developed from assessments of the actual traffic on Insat I in the mid-1980s, combined with projected growth rates. The expected mid-1990s requirement will be satisfied by two colocated Insat II satellites with a third satellite at a separate location. The two colocated satellites will appear to be a single satellite, since they will both be within ground station antenna beams. They will use opposite polarizations and offset frequencies for most transponders to allow simultaneous operation of their communications payloads. The other transponders will have opposite polarizations and the same frequencies; transmission frequencies will be chosen to keep interference levels acceptable. The broadcasting payload will be used for both television broadcasting and for transmission of multiple low-level signals for disaster warning messages, weather data dissemination, and radio program distribution.

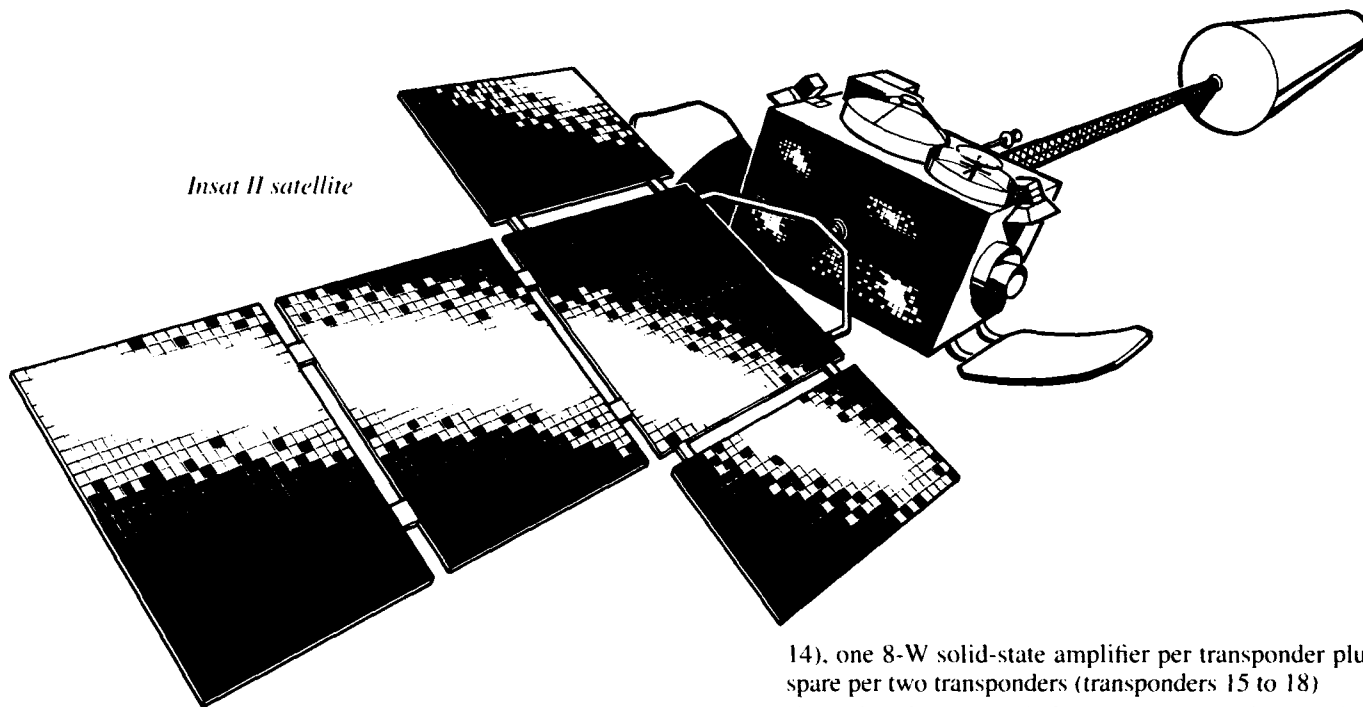
The visible and infrared radiometer is similar to the Insat I radiometer but has resolution improved to 2 km visible and 8 km infrared. A complete image scan, covering most of the earth, still

takes 23 min and is conducted once every half hour. The remaining 7 min/half hour are used for solar array motion and other actions which would disturb the radiometer's precision pointing.

The data relay transponder is similar to the transponder on Insat I. It is joined by another transponder for satellite-aided search and rescue. This transponder receives distress signals from emergency beacons and transmits them to a central rescue coordination center. It will be used in cooperation with the low-altitude transponders of the Sarsat/Cospas system, which is described later.

The goals of the Insat II program are to design, develop, build, and operate the satellite using Indian national capabilities with minimal dependence on other nations. Another goal is to launch the later Insat II satellites on an Indian launch vehicle. The appearance of the satellites is similar to Insat I. The solar array is deployed only from the south face of the satellite in order to allow a clear view to space for the radiometer thermal radiator on the north face. A solar sail on a boom helps to balance the solar radiation pressure on the array. Both the sail and the array are about 50% larger than those on Insat I. The structure of the satellite is a central cylinder with four panels joining the cylinder to the exterior faces of the body. The two large reflectors deployed from the east and west faces are for transmissions from the communications and broadcasting payloads. The smaller antenna in the center of the earth-viewing face is for reception for these payloads and transmissions for the radiometer, data relay, and search and

Insat II satellite



rescue payloads. The smaller antenna in the corner of the earth-viewing face is for the reception for the latter two payloads.

Additional information on Insat II is as follows:

Satellite

Rectangular body, $6.3 \times 5.6 \times 5.7$ ft, 75-ft span of solar array and solar sail

Approximately 2300 lb in orbit, beginning of life

Sun-tracking solar array and NiCd batteries, 1180 W at end of life in sunlight, only partial payload operation during eclipse through life

Three-axis-stabilized using two momentum wheels, one reaction wheel, and magnetic torquers; pointing accuracy 0.2 deg (roll and pitch), 0.4 deg (yaw)

Unified bipropellant propulsion for apogee maneuver and on-orbit use

Configuration

Communications (COM): twelve 36-MHz bandwidth single-conversion transponders (for colocated satellites, one has ten 36-MHz bandwidth transponders with center frequencies 20 MHz above the other satellite transponders, plus two 27-MHz bandwidth transponders) plus another set of six 36-MHz bandwidth single-conversion transponders (same frequencies on both satellites), frequency reuse by opposite polarizations on colocated satellites

Broadcasting (BR): two 36-MHz bandwidth single-conversion transponders

Data relay (DR): one transponder

Search and rescue (SAR): one transponder

Radiometer (RA): transmission of data from onboard radiometer

Transmitter

COM: 3705 to 4185 MHz (3725 to 4185 MHz on alternate colocated satellite) and 4510 to 4750 MHz

One 8-W solid-state amplifier per transponder in the lower band (transponders 1 to 12), two 8-W solid-state amplifiers summed and one spare per transponder (transponders 13,

14), one 8-W solid-state amplifier per transponder plus one spare per two transponders (transponders 15 to 18)

ERP 32 dBW (34 dBW for transponders 13, 14) minimum per transponder over the primary coverage area (approximately 80% of India)

BR: 2550 to 2630 MHz

Two active 50-W TWTAs plus one spare

ERP 42-dBW minimum per transponder over the primary coverage area

DR: 4504.2 MHz

SAR: approximately 4508 MHz

One active plus one spare 800-mW solid-state amplifier serves both DR and SAR

RA: 4501.5 MHz

One active plus one spare 800-mW solid-state amplifier

Receiver

COM: 5930 to 6410 MHz (5950 to 6410 MHz on alternate colocated satellite) and 6735 to 6975 MHz

One active plus one spare receiver for each of the two receive bands

BR: 5850 to 5930 MHz

One active plus one spare receiver

DR: 402.75 MHz

One active plus one spare receiver

SAR: 406.024 MHz

One active plus one spare receiver

Antenna

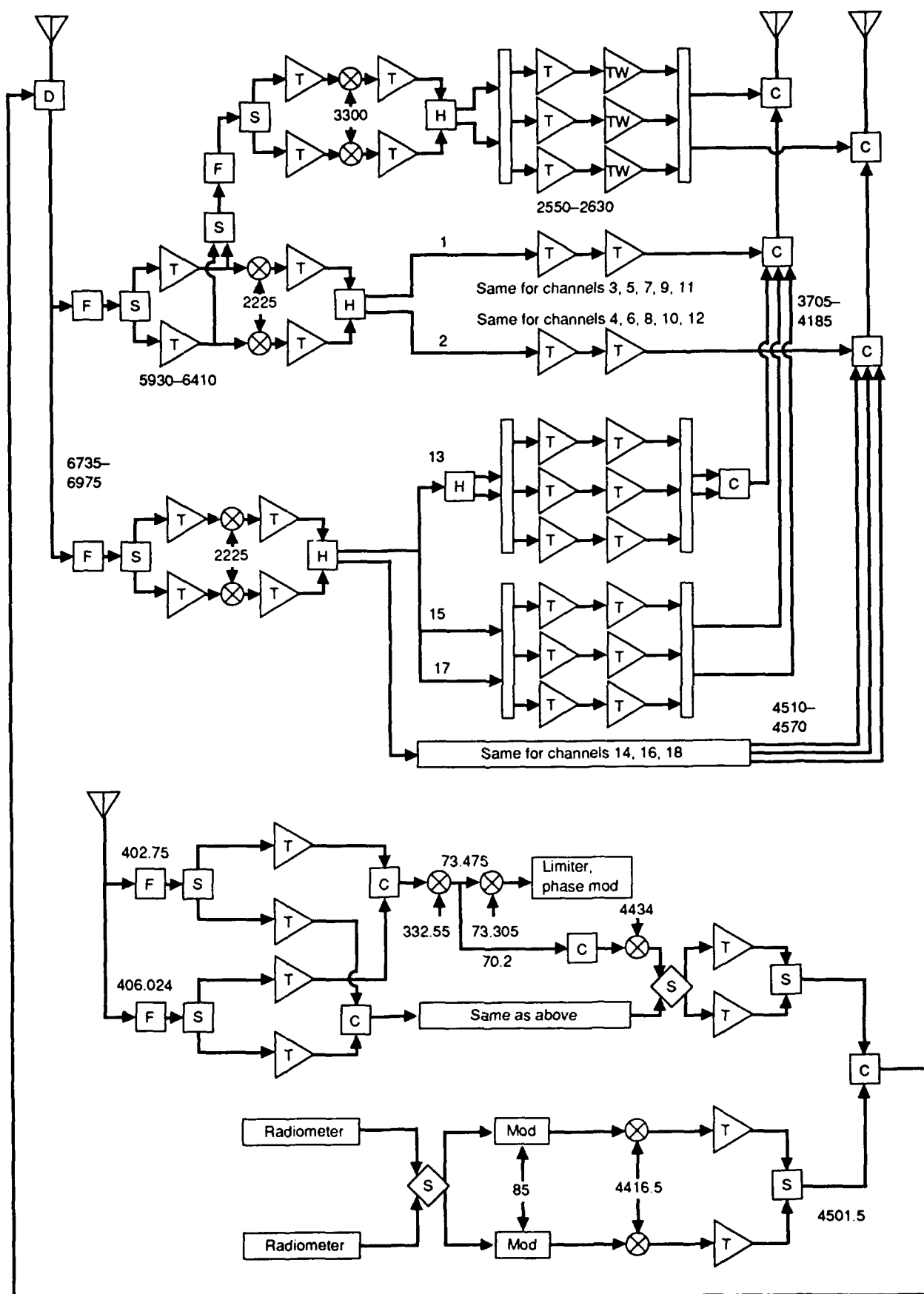
Two 5.8×5.8 -ft deployed parabolic reflectors (square except for rounded corners) for COM and BR transmissions, linear polarization (opposite polarizations on colocated satellites)

One 3-ft parabolic antenna for COM and BR reception and DR, SAR, and RA transmissions (reception on opposite polarizations on colocated satellites)

One 29-in. short backfire antenna for DR and SAR reception

Design life

Seven years



Insat II communication subsystem

Orbit

Synchronous equatorial, stationkeeping to $\pm 0.1^\circ$ N-S and E-W
Colocated satellites separated 0.05 to 0.1 deg at 74° E longitude,
third satellite at 83° E or 93.5° E longitude

Orbital history

IIA: launch scheduled early 1992

IIB: launch scheduled late 1992

IIC: launch schedule uncertain

Ariane launch vehicle for IIA to IIC

Management

Developed in India for Indian Department of Space

Operated by Department of Space

The first two Insat II satellites are designated test satellites, but their designs are identical to the next three, which are operational satellites. They will work with the same types of ground terminals currently using Insat I satellites.

* * * * *

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CHINA

Chinese experience with satellite communications [1-17] started in 1974 with the Intelsat system. Their ground terminal was manufactured outside China but assembled by the Chinese. In 1978 to 1979, China conducted experiments using the Symphonie satellite. The experiments included digital and analog voice transmission, television and facsimile transmission, and clock synchronization. Communications and propagation experiments were conducted in 1983 to 1984 using the Sirio satellite.

In 1978, there were reports that China would launch its own communications satellite in 1981. From 1978 to 1980, Chinese delegations made several visits to the United States and western Europe to discuss the purchase of communications and broadcasting satellites. However, in 1981 and 1982, China announced that these plans would be postponed because of the country's economic situation. In 1983, China leased an Intelsat transponder to begin a domestic communications network. In 1984, China launched its own communications satellite, apparently the one originally scheduled for 1981. An improved satellite was launched in 1986. Also in 1986, they purchased two Intelsat hemispheric beam transponders under Intelsat's new program of selling excess capacity.

The Chinese communication satellites are named Shiyang Tongxin Weixing (STW), which means experimental communication satellite. Generally, the satellite launched in April 1984 is considered the first Chinese communications satellite, or STW-1. However, some references count from the satellite launched in January 1984, which did not reach synchronous orbit. Since April 1984, four more communications satellites have been launched by China. STW-1 and STW-2 are sometimes designated DFH 2 (Dong Fang Hong, the east is red), and the latter three DFH 2A. (DFH 1 was apparently an early launch into low orbit which was not a communications satellite.) Beginning with the DFH 2A designation, the name Chinasat is sometimes used, perhaps to indicate a departure from the experimental status indicated by STW.

The STW satellites are spin-stabilized with a communications antenna on a despun mast along with antennas for command and telemetry. The STW-1 communications antenna was a horn; the following satellites have reflector antennas. Satellite features include the following; those attributed to the third and fourth satellites are probably also representative of the fifth.

Satellite

Cylindrical body approximately 8-ft dia., approximately 5-ft height; height including antenna approximately 10 ft

Approximately 930 lb in orbit (STW-1, -2), 1012 lb (STW-3, -4)
Solar arrays and NiCd batteries, approximately 270 W (STW-1, -2), 300 W (STW-3, -4)

Spin-stabilized

Configuration

Two (or three?) transponders, approximately 36-MHz bandwidth (STW-1, -2)

Four transponders, 36-MHz bandwidth (STW-3, -4)

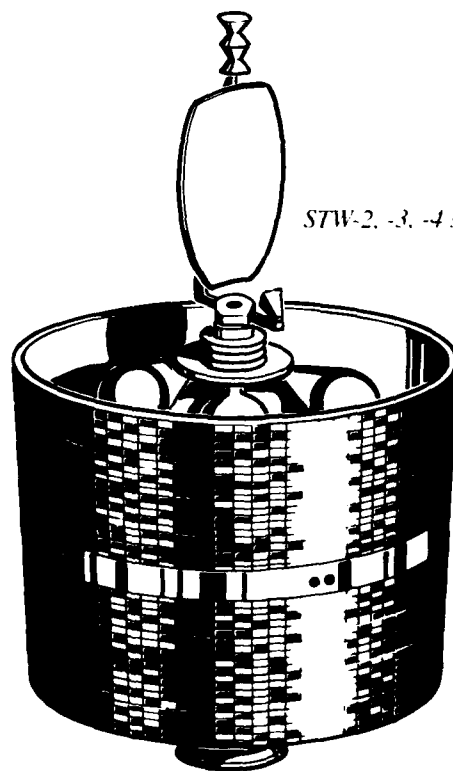
Transmitter

Approximately 4 GHz

One TWTA per transponder, 5 to 8 W (STW-1), 8 W (STW-2)

Two 10-W TWTA's and two solid-state amplifiers (STW-3, -4)

ERP 23.4/34.5/36 dBW peak (STW-1/-2/-3, -4), 32 dBW over all of China (STW-3, -4)



STW-2, -3, -4 satellite.

Receiver

Approximately 6 GHz, G/T -6 to -9 dB/K

Antenna

Earth coverage horn (STW-1)

2.5- x 4-ft reflector, beamwidth approximately 4.5×7 deg (STW -2, -3, -4)

Linear polarization

Orbit

Synchronous equatorial, stationkeeping to approximately 0.5° E-W (STW-1, -2), stationkeeping to 0.1° E-W and N-S (STW-3, -4)

Orbital history

1: launched 8 April 1984, 130° E longitude, in use after four years, perhaps still in use in 1990, inclination increased to 3.6 deg by end of 1990

2: launched 1 February 1986, approximately 85° E longitude, perhaps still in use in 1990, inclination increased to 2.3 deg by end of 1990 and E-W stationkeeping relaxed

3: launched 7 March 1988, 88° E longitude, probably in use

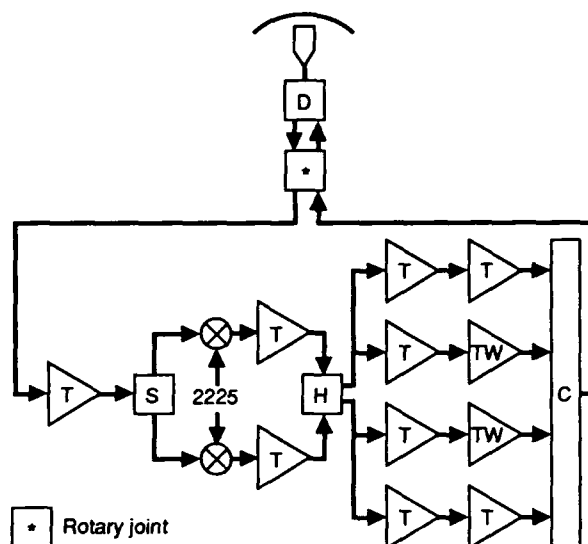
4: launched 22 December 1988, 110° E longitude, apparently in use

5: launched 4 February 1990, 98° E longitude, apparently in use
Long March 3 launch vehicle

The satellites are launched by a three-stage Chinese launch vehicle. The launch vehicle name, Long March, commemorates a long march taken by the Chinese communist army in 1934 to 1935 from southeast to northwest China. The restartable third stage uses cryogenic hydrogen and oxygen and provides all the perigee impulse and possibly some of the apogee impulse required to place the satellites in synchronous orbit. The third stage malfunctioned during the January 1984 launch and left the satellite in a 250- x 3600-nmi orbit. The entire launch vehicle is reported to be fully successful in all subsequent launches. It has been advertised for use by other nations and has attracted interest from several. In 1990, it was used for the first time to launch a non-Chinese communications satellite.

The STW-1 and STW-2 satellites were mainly used for experiments, with a moderate amount of operational traffic on the leased and purchased Intelsat transponders. The DFH-2A series, starting with STW-3, is considered a new phase, with operational traffic split between the Chinese and the Intelsat satellites. The traffic includes both telephony and television, the latter for education and training. In the eastern, coastal regions of China, terrestrial communications are well established, and the satellites are supplementary. In contrast, 80% of the land area of China is mountains and deserts, where terrestrial communications are very limited. In this part of the country, satellites are the primary means of communications.

The ground network began with about thirty terminals having antenna diameters of 20 to 40 ft. By 1990, the number had grown to about 130. These terminals are primarily for voice communications. Another 300 to 500 terminals with smaller antennas are being installed for low rate data communications. At the end of the 1980s, over 2000 terminals for television reception were in use, and four simultaneous programs were being transmitted through the STW satellites. The number of these terminals is expected to grow to 12,000; the typical antenna diameter is 20 ft.



STW-3, -4 communication subsystem.

Between 1984 and 1988, there were many reports about China's interest in larger communication satellites, perhaps moving from 4 to 6 GHz to 12 and 14 GHz, and in television broadcast satellites. Chinese delegations visited satellite manufacturers in the United States and Europe. By 1990, the plan seems to be a DFH-3 series of satellites built in China with some equipment supplied by other nations, primarily Germany. The goal of this series is to handle all domestic needs for satellite communications. These satellites will have twenty-four 36-MHz bandwidth transponders in the 4- and 6-GHz bands; the earliest a launch will occur is 1992.

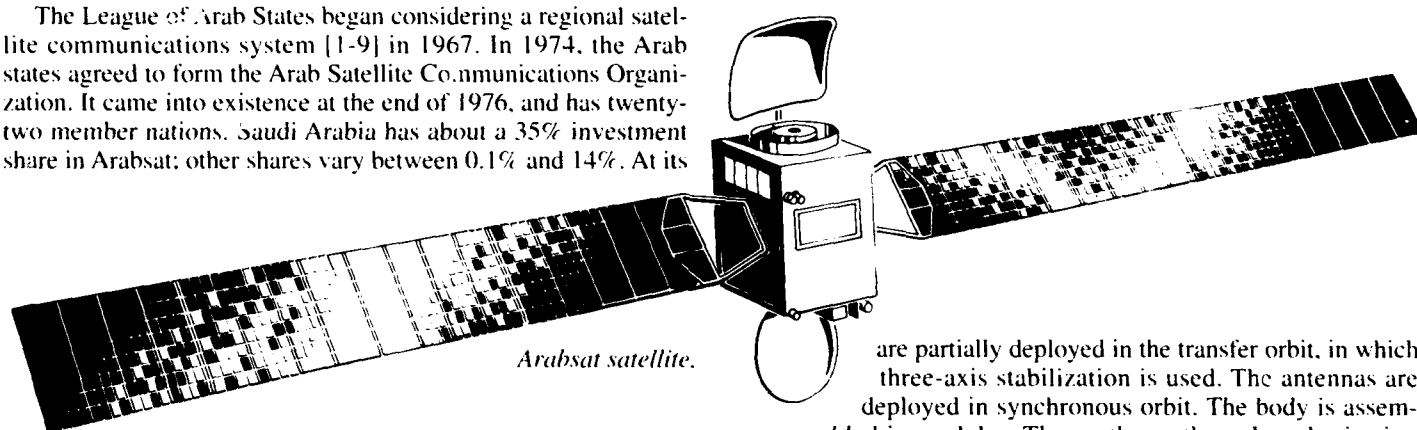
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ARABSAT

The League of Arab States began considering a regional satellite communications system [1-9] in 1967. In 1974, the Arab states agreed to form the Arab Satellite Communications Organization. It came into existence at the end of 1976, and has twenty-two member nations. Saudi Arabia has about a 35% investment share in Arabsat; other shares vary between 0.1% and 14%. At its



Arabsat satellite.

formation, technical and administrative committees began preparatory work for the Arabsat system. The objective of the system is to promote economic, social, and cultural development in the Arab world by:

- Providing reliable communication links between Arab states.
- Providing communications in rural areas.
- Developing Arab industrial capabilities in space-related technologies.
- Introducing new communications services such as video conferencing, facsimile, and remote printing of newspapers.

Within the area served by Arabsat, it is easier to establish satellite links than terrestrial links because of the great distances and large deserts.

The Arabsat Organization decided to purchase satellites, launch services, and major ground facilities internationally, but to try to develop some ground equipment within the Arab nations. This work, plus training to operate and maintain the system, will fulfill the third objective delineated. Two satellite proposals received in 1980 in response to Arabsat's request were rejected. A modified request was issued, and five proposals were received, two each from the United States and Europe and one from Canada. A contract was awarded in May 1981 for three satellites, two to be launched plus a ground-based spare.

The Arab satellite was developed by a team of European and United States companies. It includes equipment used for other satellites, particularly Intelsat V and Telecom 1. It is a three-axis-stabilized design with solar arrays and antennas. The solar arrays

are partially deployed in the transfer orbit, in which three-axis stabilization is used. The antennas are deployed in synchronous orbit. The body is assembled in modules. The north, south, and earth-viewing faces hold the communication subsystem and thermal radiators. The other three faces hold support equipment and the two large antennas. A central cylinder is a structural complement to the main rectangular structure and contains the bipropellant propulsion subsystem. The command subsystem includes a decryptor to prevent unauthorized parties from controlling the satellite. The satellite details are as follows:

Satellite

Rectangular body, 87 × 60 × 63 in., east-west span with antennas deployed approximately 18-1/2 ft, span of deployed solar arrays 69 ft

1500 lb in orbit, beginning of life

Sun-tracking solar arrays and batteries, 1300 W minimum at end of life

Three-axis stabilization using momentum wheels, ±0.1-deg antenna pointing accuracy

Unified bipropellant propulsion for apogee maneuver and on-orbit use

Configuration

C-band: twenty-five 33-MHz bandwidth repeaters

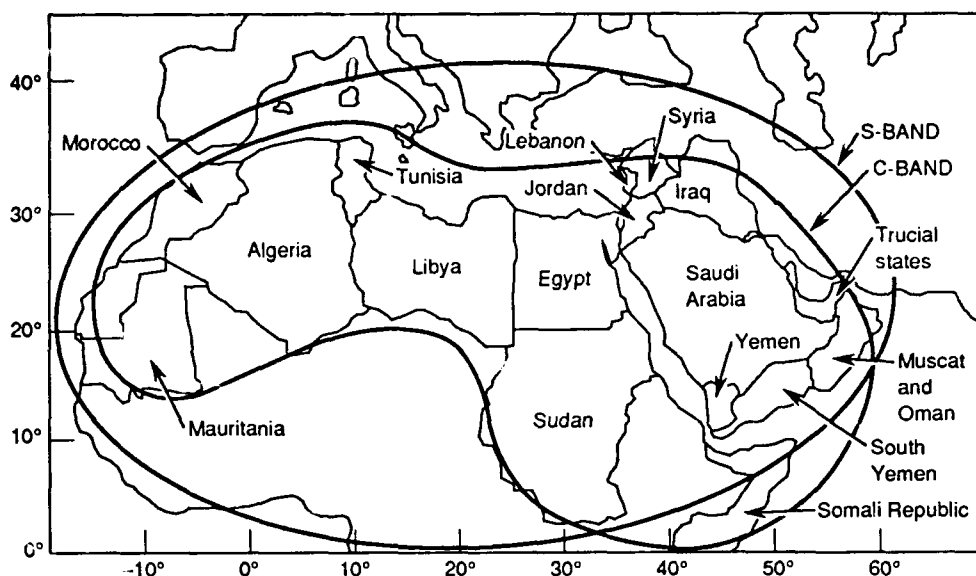
C/S-band: one 33-MHz bandwidth repeater

Dual-polarization frequency reuse in C-band

Capacity

C: 8000 voice circuits plus seven TV signals

C/S: one TV signal



Arabsat service area.

Transmitter

C: 3700 to 4198 MHz, 8.5-W output per repeater, 31 dBW minimum ERP per repeater at edge of coverage

C/S: 2560.5 or 2634.5 MHz, switchable by ground command, approximately 80-W output via summing any two of three 50-W TWTs, 41 dBW minimum ERP at edge of coverage

Receiver

C: 5945 to 6423 MHz

C/S: 5927 to 5960 MHz

G/T ≥ 7.5 dB/K over coverage area

Antenna

One offset-fed parabolic reflector for C-band transmit, 56-in. square with rounded corners; thirteen feed horns; 23 dB gain at edge of coverage, circular polarization

One offset-fed parabolic reflector for C-band reception, 51-in. dia., seventeen feed horns, 23 dB gain at edge of coverage, circular polarization

One planar slotted waveguide array for S-band transmit, 31 x 47 in., 22.7 dB gain at edge of coverage, linear polarization

Design life

Seven years

Orbit

Synchronous equatorial, stationkeeping to $\pm 0.1^\circ$ N-S and E-W

Orbital history

1A: launched 8 February 1984, 19° E longitude

Ariane launch vehicle

1B: launched 17 June 1984 (deployed from Shuttle 18 June), 26° E longitude

Shuttle/PAM-D launch vehicle

1C: launch scheduled early 1992

Ariane launch vehicle

Management

Developed for Arab Satellite Communications Organization (Arabsat) by Aerospatiale with Ford Aerospace and Communication as a major subcontractor

Operated by Aerospatiale for two years, then by Arabsat

The Arabsat communication subsystem uses the 4- and 6-GHz frequency bands, plus one downlink near 2.5 GHz. The uplink consists of thirteen 33-MHz bandwidth channels spaced 37 MHz center-to-center on each of two polarizations. They are received via the circular 6-GHz antenna and fed to redundant receivers. Twenty-five channels are retransmitted at 4 GHz using the square, deployed antenna. The other channel may be switched to either of two frequencies near 2.6 GHz and is transmitted through the rectangular planar antenna on the earth-viewing face of the satellite body. The switchable frequencies allow this channel to be used on both orbiting satellites without any potential for mutual interference.

In late 1981, a temporary problem arose concerning whether or not the United States subcontractor would be granted an export permit for the equipment it was developing. The rationale was that Libya and South Yemen, considered unfriendly to United States interests, were part of Arabsat, and that the satellite might have a military use. Within six months, the issue was resolved in favor of the export permit. Satellite development continued and two satellites were launched in 1984, one each by Ariane and the Shuttle. The first satellite experienced solar array deployment problems, which were overcome, and attitude control problems, corrected by switching to a redundant unit. Both satellites are operational although, normally, only one will be active.

The 4/6-GHz transponders' allocation was ten to international telephony using FDM/FM/FDMA, two to international telephony using SCPC/FM/FDMA, one for international television distribution, three for emergency communications, and nine for domestic use by Arabsat members. The one 2.5-GHz channel was planned for television broadcasting; primarily for community reception. All television transmissions use FM. International transmissions are between terminals supplied by the members, typically one per member, with a 36-ft antenna. Smaller transportable terminals also may be used. The 2.6-GHz television reception terminals may have 8-ft antennas. Arabsat had two control terminals built, each with two antennas. The primary one is in Riyadh, Saudi Arabia; the alternate is in Tunis, Tunisia. The satellite contractor was responsible for satellite control for the first two years, during which it would train Arabsat personnel in satellite operations. This control contract was extended into a third year; subsequently, satellite control has been done by citizens of Arab nations.

Although the Arabsat system had great promise, during the first five years after launch the satellites were underutilized. By 1989, approximately one-third of the capacity of one satellite was in use, mostly for telephony. Several reasons contributed to this underutilization. One is that satellite charges are no less than those of Intelsat, giving no incentive to move traffic from Intelsat to Arabsat. Another is that some Arab nations built and are building new terrestrial communications facilities which divert traffic from Arabsat. A third reason is that Egypt was expelled from the Arab League in 1979 for signing the Camp David agreements with Israel. Although later returned to membership, Egypt never made the expected large use of, and investment in, Arabsat. Through 1989, the 2.5-GHz television broadcasting capability had not been used at all, because there was no agreement on programming that could be acceptable to all the member nations. The disagreements were both political and religious.

Because of the underutilization, Arabsat revenues are far below past expectations. Hence, the organization is working to maximize the lifetimes of the two satellites in orbit while encouraging additional uses to boost revenues. The third satellite is in storage on the ground and is scheduled to be launched in 1992.

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BRAZIL

Long-distance communications in Brazil were transformed from primitive to modern between 1965 and 1985. In 1965, when Brazil joined Intelsat and created the state-owned Empresa Brasileiro de Telecomunicacoes (Embratel), high-frequency radio was the common long-distance transmission medium. In 1969, Brazil started using Intelsat for international links. By 1972, a new microwave system linked major Brazilian cities, but troposcatter was the means for communicating with most interior points of the country. Some satellite communication experiments were conducted in the early 1970s using ATS 3. Domestic satellite communications started in 1974 with a leased Intelsat transponder and two earth terminals. By 1979, the system had expanded to 2.5 transponders and six terminals. In another five years, it had expanded to seven transponders and over 200 terminals, most for television reception. In the mid-1970s, the government requested, and received, proposals for its own satellite but then cancelled the project for economic reasons. However, as the use of Intelsat increased, the economics of the domestic satellite became better, relative to the lease costs. In addition, a dedicated satellite would provide greater operational flexibility. Therefore, in 1981, a new set of proposals was received, and in the next year a satellite development contract was awarded. The satellite is a part of the Sistema Brasileiro de Telecomunicacoes por Satellite (SBTS), more commonly called Brasilsat [1-7].

The satellite is a spin-stabilized design used for many other domestic satellites. The solar panel consists of two cylinders; the outer one surrounds the inner for minimum size during launch and is deployed in orbit. A thermal radiator occupies the middle portion of the inner solar panel, within which is the basic structure of the satellite. Support subsystems are mounted on the struc-

ture, which includes a central bearing and motor to despin the communication subsystem equipment shelf. The antenna is in an open area at the top of the inner solar panel at launch and is rotated to its operating position when the satellite reaches synchronous orbit.

The communication subsystem has twenty-four repeaters. The 4- and 6-GHz frequency bands are used, with dual-polarization frequency reuse. An array of feed horns, in combination with the large reflector, form a beam optimized for coverage of Brazil. The receivers and transmitters, and their redundancy arrangements, are the same as on other modern satellites that use the same frequency band. The satellite details are as follows:

Satellite

Cylinder, 85-in. dia., 116-in. height (stowed), 23-ft height (deployed)

1470 lb in orbit, beginning of life

Solar cells and NiCd batteries, 985 W beginning of life, 800 W after eight years

Spin-stabilized, gyrostabil, approximately 60-rpm spin rate, antenna pointing accuracy ± 0.05 deg

Solid rocket motor for apogee maneuver and hydrazine propulsion for on-orbit use

Configuration

Twenty-four 36-MHz single-conversion repeaters, dual-polarization frequency reuse

Transmitter

3702 to 4198 MHz

Five 9-W TWTs for each group of four repeaters
ERP 34 dBW per repeater over >90% of Brazil

Receiver

5927 to 6423 MHz

Four receivers (two active, two spare)

G/T ≥ -4 dB/K

Antenna

Two 71-in.-dia. parabolic reflectors sharing the same aperture using orthogonal linear polarizations, beam shaped to Brazil, 27-dB gain over >90% of the country, >24-dB gain everywhere, fifteen feed horns

Design life

Eight years

Orbit

Synchronous equatorial, stationkeeping to $\pm 0.1^\circ$ (or better) N-S and E-W

Orbital history

1: launched 8 February 1985, in use, 65°W longitude

2: launched 28 March 1986, spare, 70°W longitude

Ariane launch vehicle

Management

Developed by Spar Aerospace for Embratel

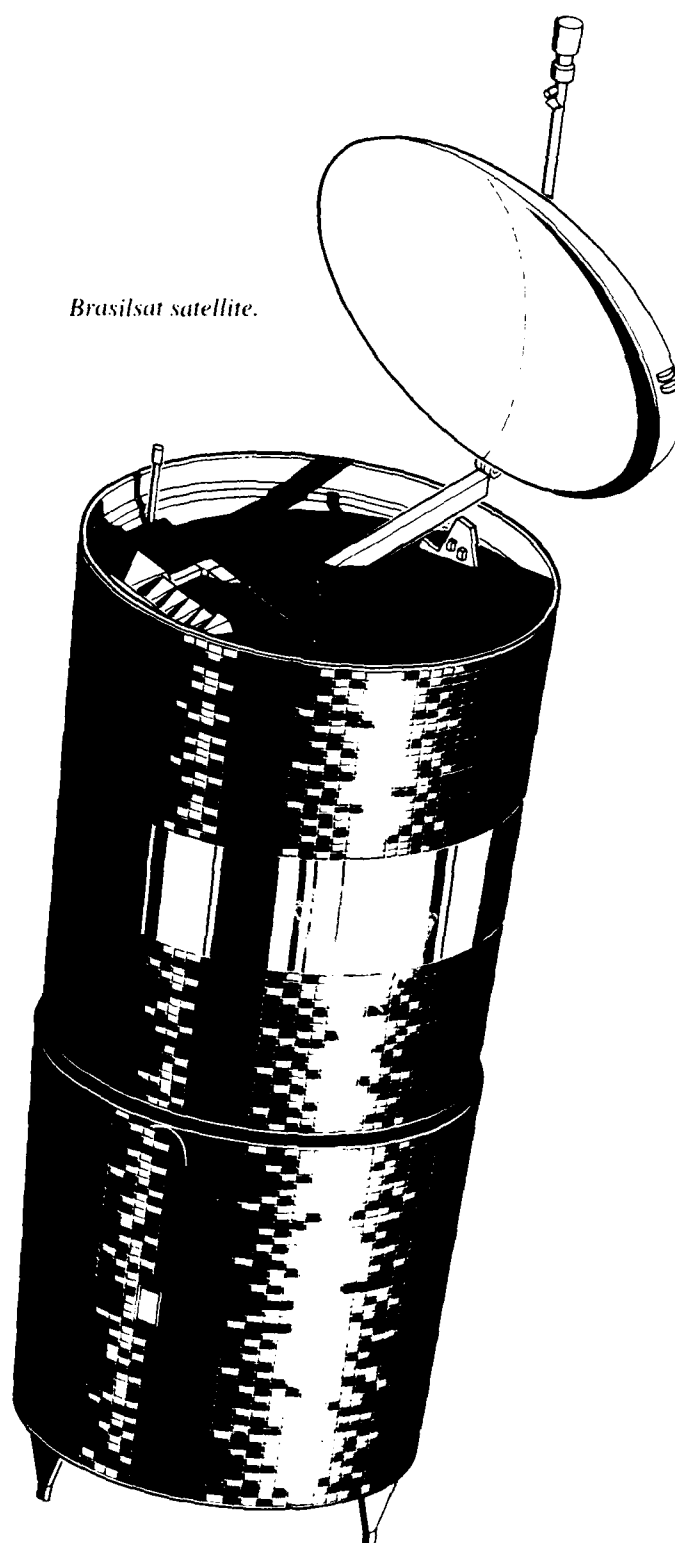
Operated by Spar Aerospace for six months, then by Embratel

The satellites are controlled from a system operations center in Rio de Janeiro. Much of the satellite control equipment was provided by the satellite contractor, who operated the satellites for their first six months in orbit while training Brazilian operators. Primary uses of the satellites are long-distance telephony and television distribution. Telephony between major cities uses FDM/FM, but other telephony and data links use SCPC/FM. The two satellites have been underutilized, with the second being used for occasional tests only. About half of the first satellite is used for telephony and the other half split between television networks, teleconferencing and spare repeaters, plus one repeater for military use. Reasons for the underutilization are at least twofold. One is that Embratel is a monopoly with strict control of satellite use, which prevents the development of the many commercial applications which have flourished in some countries. The other reason is that the social ministries in the government were not involved in planning for the use of the satellites and now still lack the budget and expertise to develop social applications.

Brazilian content of its first earth terminals, in the 1970s, was small. Guided by a definite intention to be self-sufficient in space-related technologies, Brazil became almost entirely self-sufficient in earth terminal manufacturing in the first half of the 1980s. Because of the limitations mentioned above on use of the satellites, the number of terminals has grown slowly.

In 1989, Brazil concluded a competition for its second generation of satellites and announced its choice of contractor and launch vehicle. The contractor is the same one that built the first two satellites. The second-generation satellites were stated to have twenty-eight repeaters at 4 and 6 GHz plus one at 7 and 8 GHz for the Brazilian military.

By the beginning of 1991, construction of the satellites had not started. The delay was due to extended negotiations on the satellite configuration and offset work to Brazilian contractors and to

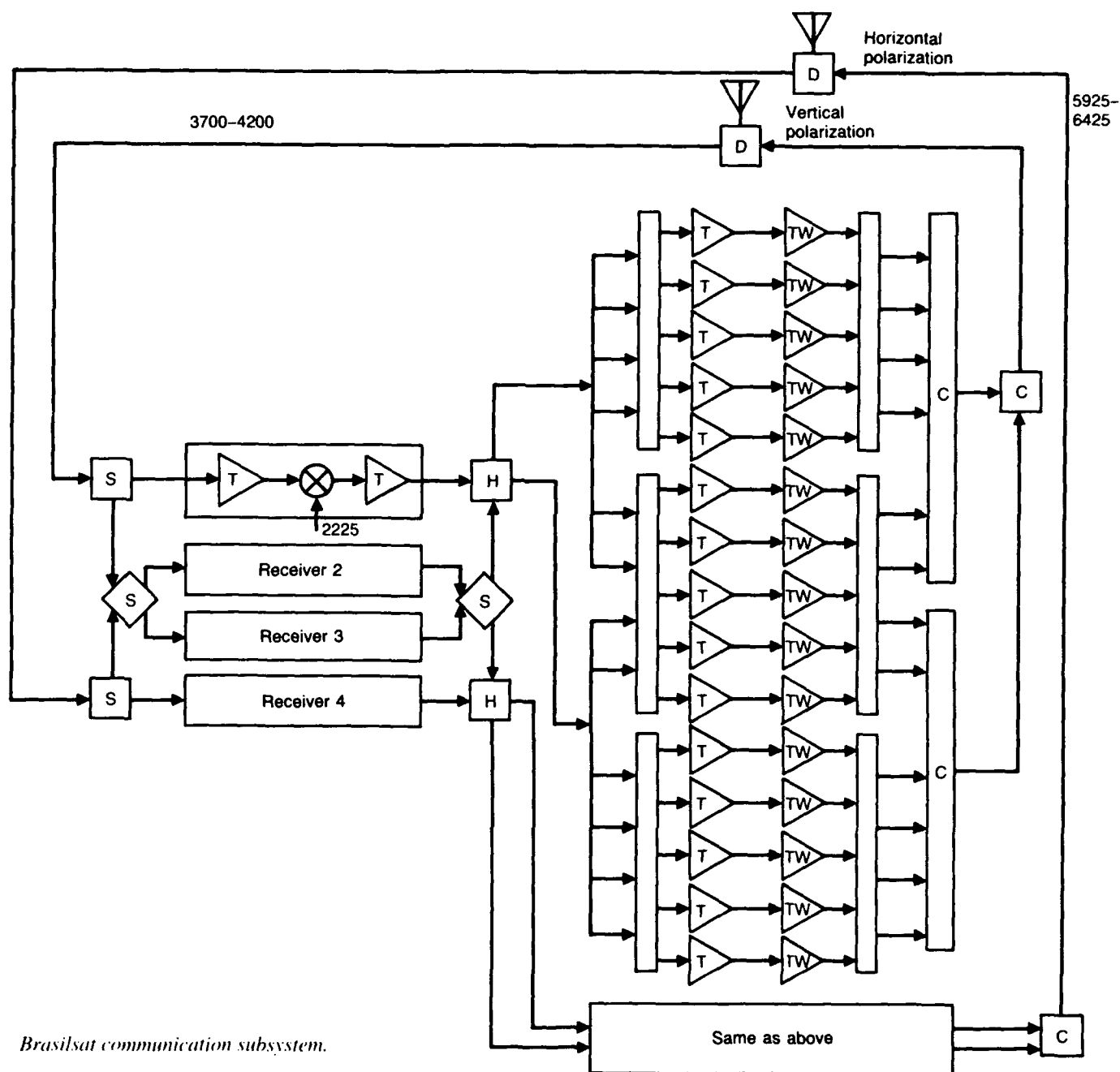


Brasilsat satellite.

problems in arranging financing. Construction was expected to begin in 1991, with the first launch in 1994 and the second in 1995.

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Brasilsat communication subsystem.

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MEXICO

Mexico started domestic use of satellite communications in 1980, by leasing Intelsat capacity on a satellite that was moved to 53°W longitude to provide domestic services for Western Hemisphere nations. Mexico also owns one transponder on a United States domestic satellite that is used for transmission of television to the United States. In the spring of 1983, a contract was awarded for construction of a Mexican domestic communications satellite [1-6]. This satellite, and the system of which it is a part, is called Morelos, in honor of an important person in Mexican history.

The satellite shares the same design as many others, e.g., Anik C, SBS, Westar IV, Palapa B, and Aussat. It is launched as a compact cylinder. In synchronous orbit the extra solar array, which surrounds the main body at launch, is deployed along three tracks mounted around the main body. Also, the antenna assembly is unfolded from its launch position against one end of the body. The large reflector and its feed horns are attached to an equipment shelf upon which the communications electronics are mounted. This shelf is despun to maintain the proper east-west antenna pointing. North-south pointing is accomplished by a motor located at the hinge where the reflector is attached to the satellite. Pointing information is obtained by tracking a 6-GHz beacon transmitted from the ground. Equipment, other than the communications subsystem, is mounted to the spinning structure of the satellite.

Among all the satellites of this design, the Mexican satellite is the first to use two sets of communication frequencies. Most 4/6-GHz domestic communication satellites have twelve transponders on each polarization. The Mexican satellite has twelve transponders on one polarization but only six on the other. The six transponders have twice the bandwidth (72 MHz) of the twelve (36 MHz); hence, the 4/6-GHz spectrum is fully used. Nevertheless, the reduction in 4/6-GHz transponders allows the satellite to carry an additional payload—four 108-MHz bandwidth 12/14-GHz transponders. This combination of transponders in two frequency bands maximizes the transponder bandwidth in this size satellite. The same approach is used by another manufacturer in the Spacenet and ASC satellites.

The large reflector is used for 6-GHz reception and 4- and 12-GHz transmission. Thirteen feed horns are used for vertical polarization reception, including both communication signals and the tracking beacon. Eight horns are used for horizontal polarization reception and dual-frequency transmission. The multiple feed horns shape the beam to Mexican geography. The beam patterns for both transmission frequencies are shown. Reception at 14 GHz is through a planar slotted array composed of thirty-two square segments. It is mounted just above the feed horns used with the large reflector. The multifrequency reflector and planar array replaced the initial Morelos design, which had separate 4/6-GHz and 12/14-GHz reflectors. The satellite and payload details are as follows:

Satellite

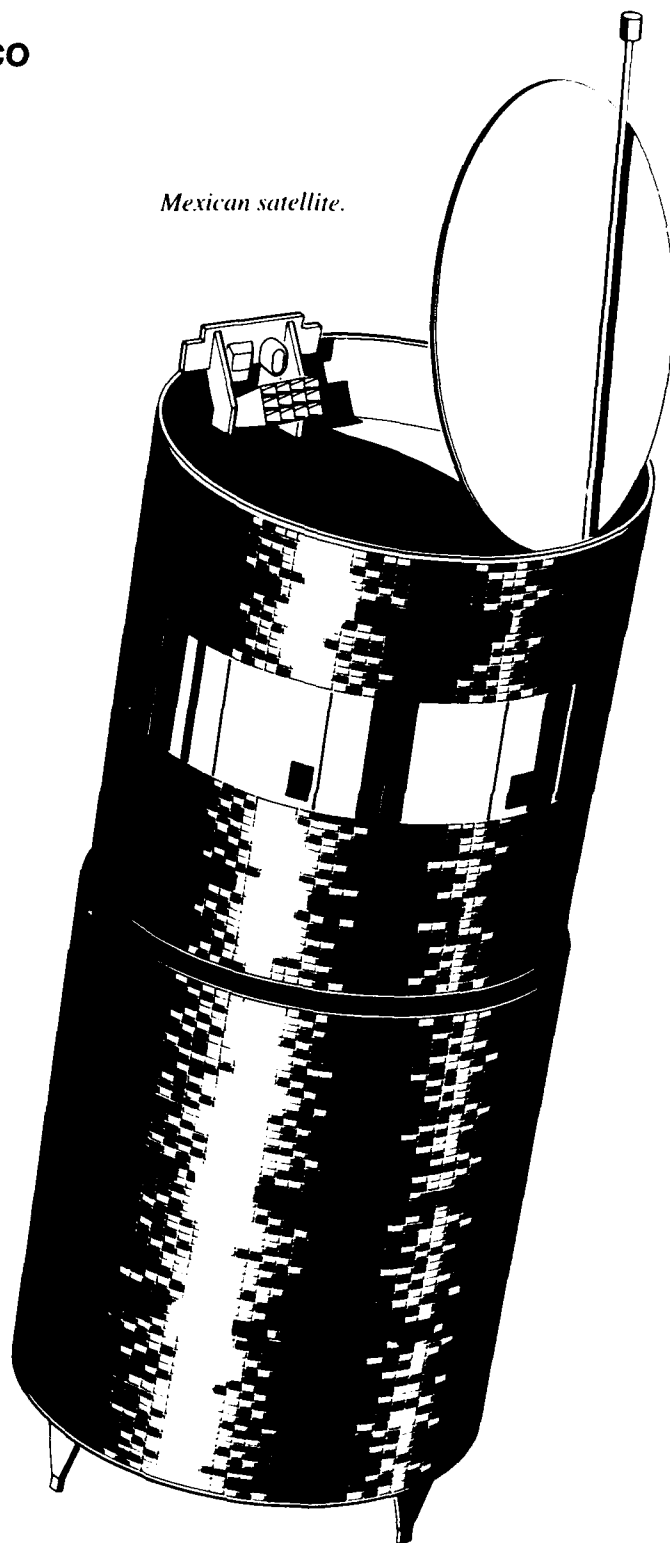
Cylinder, 85-in. dia., 112-in. (9 ft. 4 in.) height in launch configuration, 261-in. (21 ft 9 in.) height when deployed

Approximately 1465 lb in orbit, beginning of life

Solar cells and NiCd batteries, 940 W beginning of life, 760 W after ten years

Spin-stabilized, gyrostat, approximately 60 rpm spin rate, antenna pointing accuracy ± 0.05 deg

Mexican satellite.



Configuration

4/6 GHz: twelve 36-MHz bandwidth single-conversion repeaters and six 72-MHz bandwidth single-conversion repeaters on orthogonal polarizations

12/14 GHz: four 108-MHz bandwidth single-conversion repeaters

Transmitter

4/6 GHz: 3700 to 4200 MHz

Seven 7-W TWTs for each set of six 36-MHz repeaters, 36-dBW ERP per repeater at edge of coverage

Eight 10.5-W TWTs for the six 72-MHz repeaters, 39-dBW ERP per repeater at edge of coverage

12/14 GHz: 11.7 to 12.2 GHz

Six 20-W TWTs for the four repeaters, 44-dBW ERP per repeater at edge of coverage

Receiver

4/6 GHz: 5925 to 6425 MHz

Four receivers (two on, two spare)

FET preamplifiers

G/T +1 dB/K over all of Mexico

12/14 GHz: 14.0 to 14.5 GHz

Two receivers (one on, one spare)

FET preamplifiers

G/T +1 dB/K over all of Mexico

Antenna

4/6 GHz: one 71-in. dia. offset-fed parabola with two polarization sensitive surfaces, twenty-one feed horns shape beam for Mexican coverage, linear polarization

12/14 GHz: shares the 4/6-GHz horizontal polarization reflector and seven of eight feed horns for transmission; 16- x 40-in. vertical polarization planar array for reception

Edge of coverage gain, transmit and receive, both frequency bands, is 29 to 32 dB

Design life

Ten years (fuel load nine years)

Orbit

Synchronous equatorial, stationkeeping to $\pm 0.1^\circ$ (or better) N-S and E-W

Orbital history

1: launched 17 June 1985 (deployed from Shuttle, 17 June), 113°W longitude, in use

2: launched 26 November 1985 (deployed from Shuttle, 27 November), 117°W longitude

Shuttle/PAM launch vehicle

Management

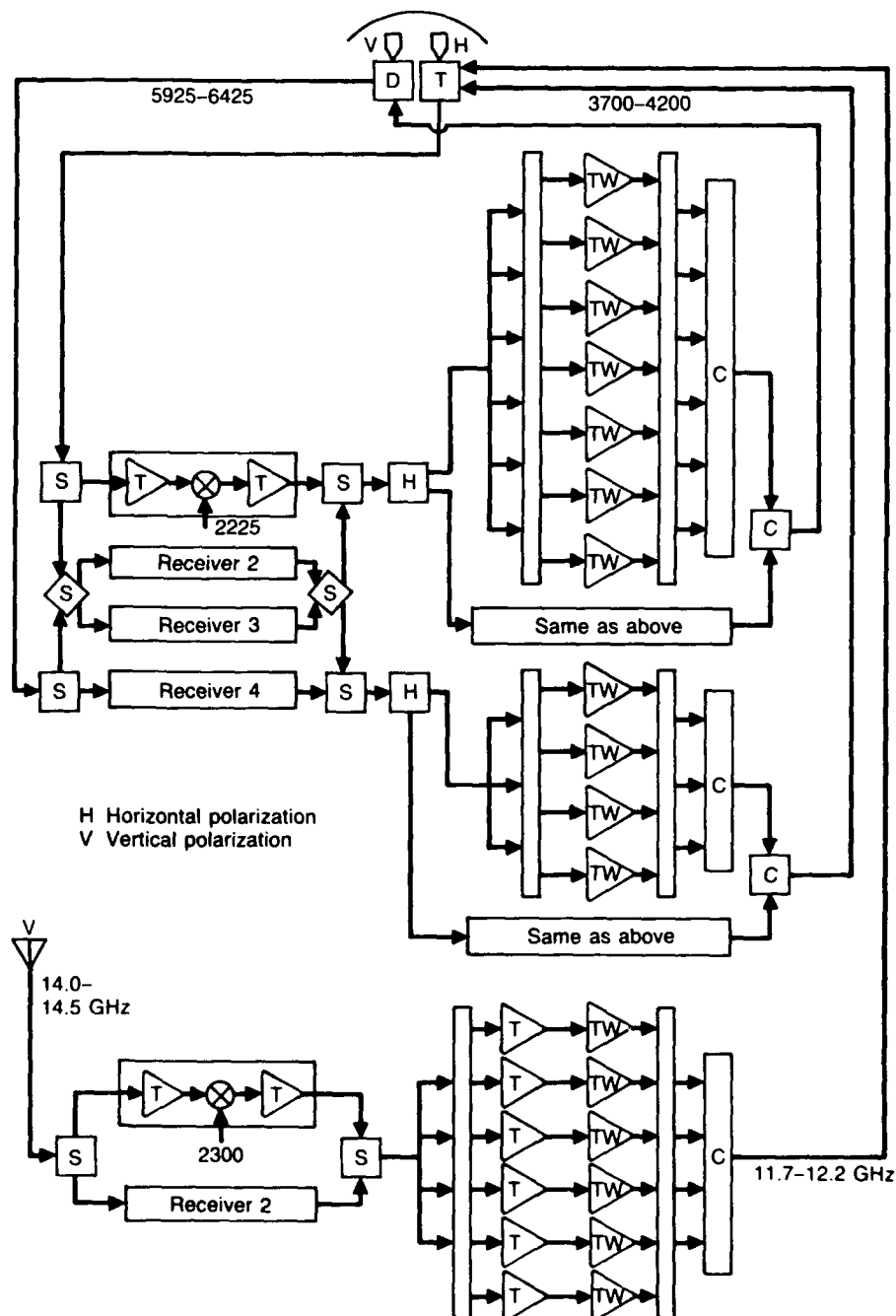
Developed by Hughes Aircraft Company for Secretaria de Comunicaciones y Transportes
Operated by Secretaria de Comunicaciones y Transportes

Morelos 1 was launched in June 1985. After testing, all traffic was transferred to it from the Intelsat satellite. Morelos 2 was launched in November 1985 and put into a drifting storage orbit just above synchronous altitude. In 1986, it was stabilized at 116-deg longitude in an orbit with a few degrees inclination. That orbit was properly phased, so that the inclination decreased to zero by 1990 due to natural forces. This five years of orbital strategy was the best choice for Morelos 2

to take advantage of its scheduled launch, yet not use fuel for stationkeeping until its communication capacity is required.

The Morelos system provides services to both urban and rural areas. Urban areas, cities and towns with populations of more than 2500, have existing terrestrial communications. Morelos provides a many-fold capacity increase for television, trunk telephony, data transmission, and private networks. Rural areas typically do not have terrestrial telephone or television service. Morelos can provide these plus communications for health care and to promote the development of agriculture, the mining and oil industries, and tourism.

The control center for Morelos is located near Mexico City. About 230 4/6-GHz earth terminals in use with the Intelsat lease



Mexican satellite communication subsystem.

were transferred to Morelos. Only seven had transmission equipment. The others were equipped only for television reception, but the equipment for two-way telephony can be added easily. Their number will increase, in addition to many other earth terminals to receive television transmission at 12 GHz. The 12-GHz terminals will have 10-ft antennas, whereas the 4/6-GHz terminals have antenna diameters between 15 and 36 ft.

After three years of operation, the first satellite was used much less than had been anticipated. The primary use was television distribution; secondary uses were telephony, data, and radio program distribution. Several causes contributed to the underutilization. First, although many worthwhile uses had been identified in planning the Morelos system, detailed work to implement them had not been done. Second, until 1988 only the government was

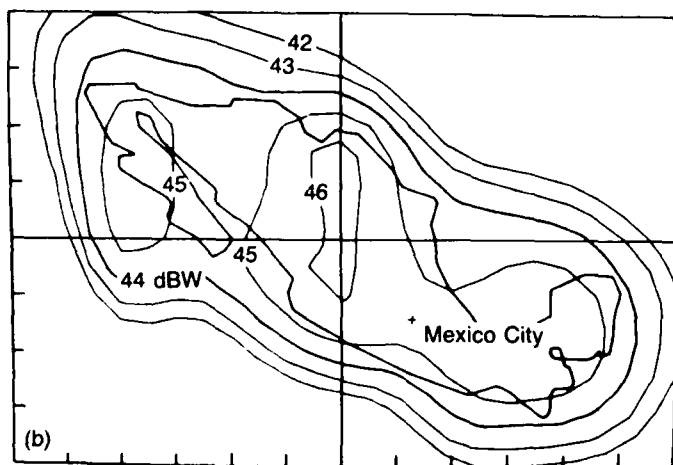
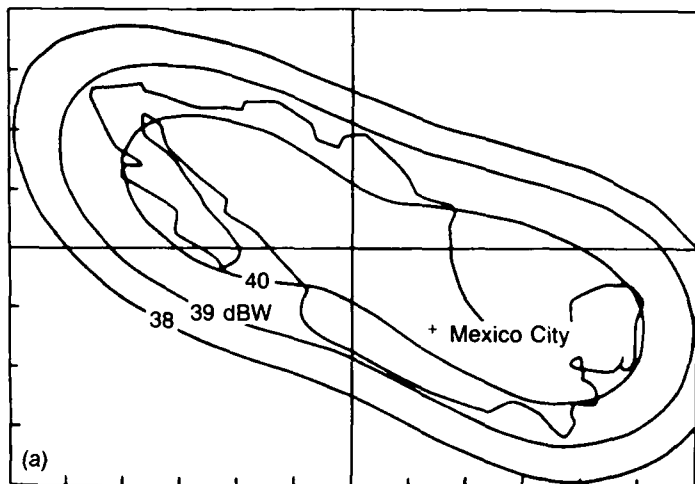
allowed to own earth terminals, and its budget restrictions did not allow it to buy enough to increase satellite usage. Some private companies bought terminals and gave them to the government in order to be able to use the satellite. Third, the government agencies responsible for social uses of the satellites did not have enough interest or budget to develop anything. Thus, although social uses were projected to require 30% of the satellite capacity, only one health care project was operating. Fourth, some government agencies, unable to cooperate with the satellite operator, expanded their terrestrial communications networks. The first three of these causes also underlie the lack of utilization of the Brazilian satellite.

Use of the Morelos system is increasing slowly, which impacts the planning for replacement of the satellites. Replacement launches are desirable in 1994 to 1996 to insure continuity of service, but the current underutilization reduces revenues and discourages the investments necessary for new satellites. In the fall of 1990, a request for proposals was issued for new satellites; and in summer 1991, a contract was awarded, and it was announced that two Solidaridad satellites will be launched in 1994.

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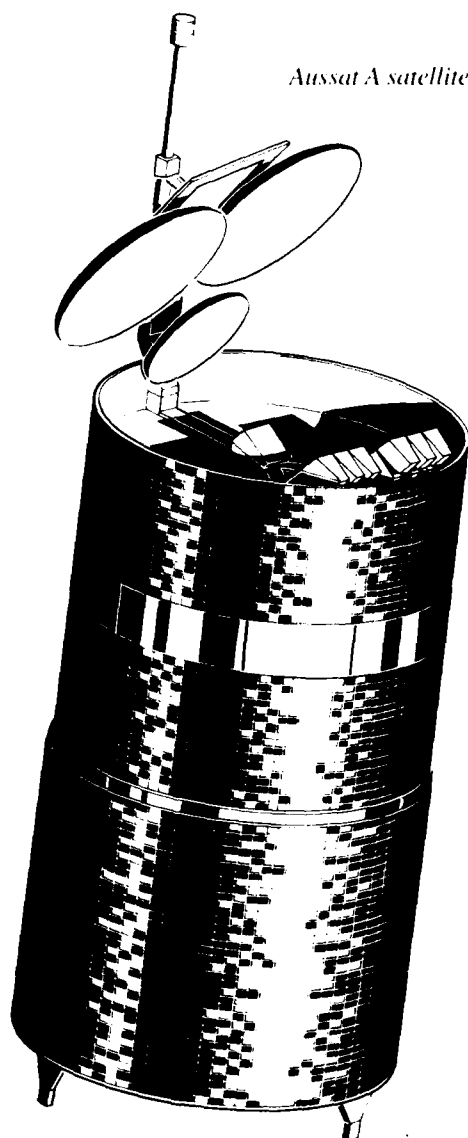
Mexican satellite coverage. (a) C-band transmit coverage (72 MHz repeaters); (b) K-band transmit coverage.



AUSTRALIA (AUSSAT)

In the large undeveloped and sparsely populated regions of Australia, means of communications and broadcasting were either unreliable or nonexistent. Satellite communications can provide the needed improvements at lower cost than terrestrial alternatives. The first study of an Australian domestic system was conducted in 1966. In 1969, Australia began routing some transcontinental telephone circuits through the Intelsat system. During 1970, experiments were conducted using ATS 1 to gather data that would be useful in planning a domestic satellite system.

Studies continued through the 1970s [1-3]. In mid-1979, the government made a decision to implement a system. In the fall of 1979, the Canadian Hermes Satellite (CTS) was used for demonstrations of television broadcasting to small terminals at numerous locations. Distribution of television to fifty isolated communities began in 1980 using an Intelsat satellite. Between mid-1979 and April 1982, satellite specifications were developed, a government-owned operating company (Aussat Proprietary Limited) was formed, and a satellite contract was signed.



Aussat A satellite.

The satellites were originally called Aussats. With the development of a second generation, the first satellites were designated Aussat A. The Aussat A design [4-18] is basically the same as many others, e.g., Anik C, Telstar 3, Galaxy, and Palapa B. It is a dual-spin satellite with a deployable solar array. Support subsystems are mounted on the spinning section, and the communication subsystem is on a despun platform. The three dual-polarized reflectors are mounted on a common structure which is deployed in orbit.

The satellite has transmit antenna beams for all six of its service areas and receive antenna beams for national and Papua New Guinea (PNG) coverage. The two larger reflectors seen in the satellite figure are used for PNG and spot beams. The smallest reflector is used for national beams.

Aussat A has fifteen communications transponders, eleven low power and four high power. Because of the two types of transponders and the many antenna beams, the communication subsystem has many switching matrices. The receivers all cover the entire 500-MHz uplink bandwidth, with one connected to each of the three antenna beams. The input switch for Transponders 1 through 8 connects each transponder to either the national or PNG receiver output. The uplinks for these transponders use one polarization; the uplinks for Transponders 9 through 15 use the other. The high-power (30-W) transmitters and their redundancy

switches are in the center of the diagram; the low-power (12-W) transmitters are in the upper and lower parts of the diagram. Following the transmitters are the output switches, which connect each transponder to one antenna beam. The transponders, with a bandwidth of 45 MHz, are spaced 64 MHz center-to-center in each polarization. This wide spacing was necessary to make the transponder switching and combining hardware practical. In satellite A3, additional feed horns were added to form a Southwest Pacific beam as an alternative to the PNG beam. Satellite and communications details are as follows:

Satellite

Cylinder, 85-in. dia., 111-in. height stowed, 260-in. (21 ft 8 in.) height deployed

1430 lb in orbit, beginning of life

Solar cells and NiCd batteries, approximately 1050 W at beginning of life, approximately 860 W minimum at end of life

Spin-stabilized, gyrostabilized, antenna pointing to ± 0.05 deg or better

Solid rocket motor for apogee maneuver and hydrazine propulsion for on-orbit use

Configuration

Fifteen 45-MHz bandwidth single-conversion transponders, dual-polarization frequency reuse

Transmitter

12.254 to 12.748 GHz

Eleven active plus two spare transmitters with 12-W TWTs for Transponders 1 through 6 and 9 through 13

Four active plus two spare transmitters with 30-W TWTs for Transponders 7, 8, 14, 15

ERP per transponder at edge of coverage: 34/38 dBW in national beams (2 to 3 dB higher over >90% of country) 41/45 dBW in Papua New Guinea beam, 29/34 dBW in southwest Pacific beam (A3 only), 38/42 dBW in spot beams (5 dB higher in most areas) (12/30-W TWT)

Receiver

14.002 to 14.496 GHz

Three active plus two spare receivers

G/T at edge of coverage: -3 dB/K in national beams, -1 dB/K in Papua New Guinea beam

Antenna

Three offset-fed parabolic reflectors: one 24-in. dia. for national beams receive and transmit; one 39-in. dia. for Papua New Guinea beam and southwest Pacific beam (A3 only) transmit and northeast and southeast spot beams transmit; one 43-in. dia. for Papua New Guinea beam and southwest Pacific beam (A3 only) receive, and west and central spot beams transmit; all use linear polarizations; 32-dB minimum cross-polarization isolation

Design life

Ten years (fuel load for eight years)

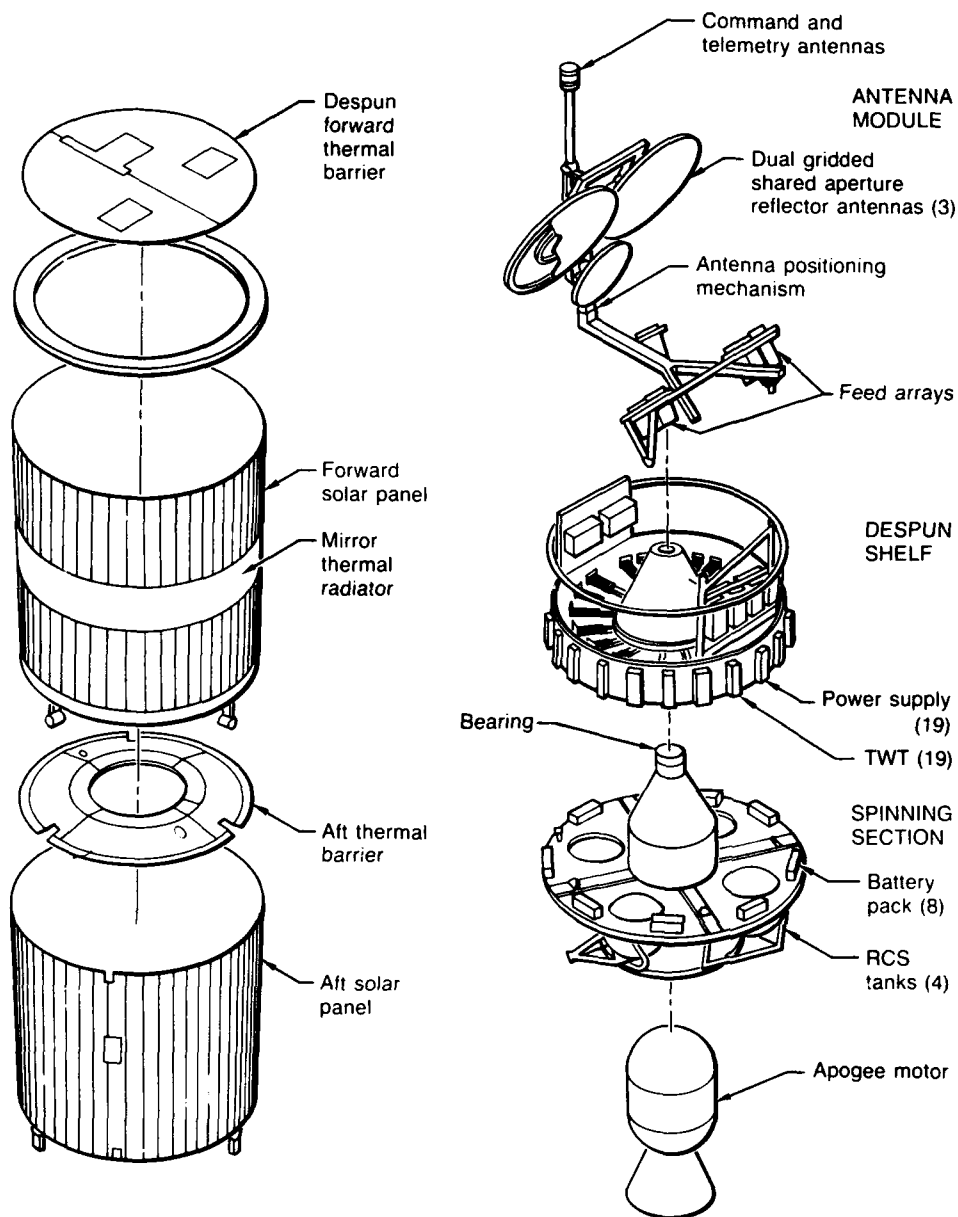
Orbit

Synchronous equatorial, stationkeeping to $\pm 0.05^\circ$ N-S and E-W

Orbital history

A1: launched 27 August 1985 (deployed from Shuttle, 27 August), in use at 160° E longitude

A2: launched 26 November 1985 (deployed from Shuttle, 27 November), in use at 156° E longitude



Aussat A satellite details.

Shuttle/PAM-D launch vehicle

A3: launched 15 September 1987, in use at 164°E longitude

Ariane launch vehicle

Management

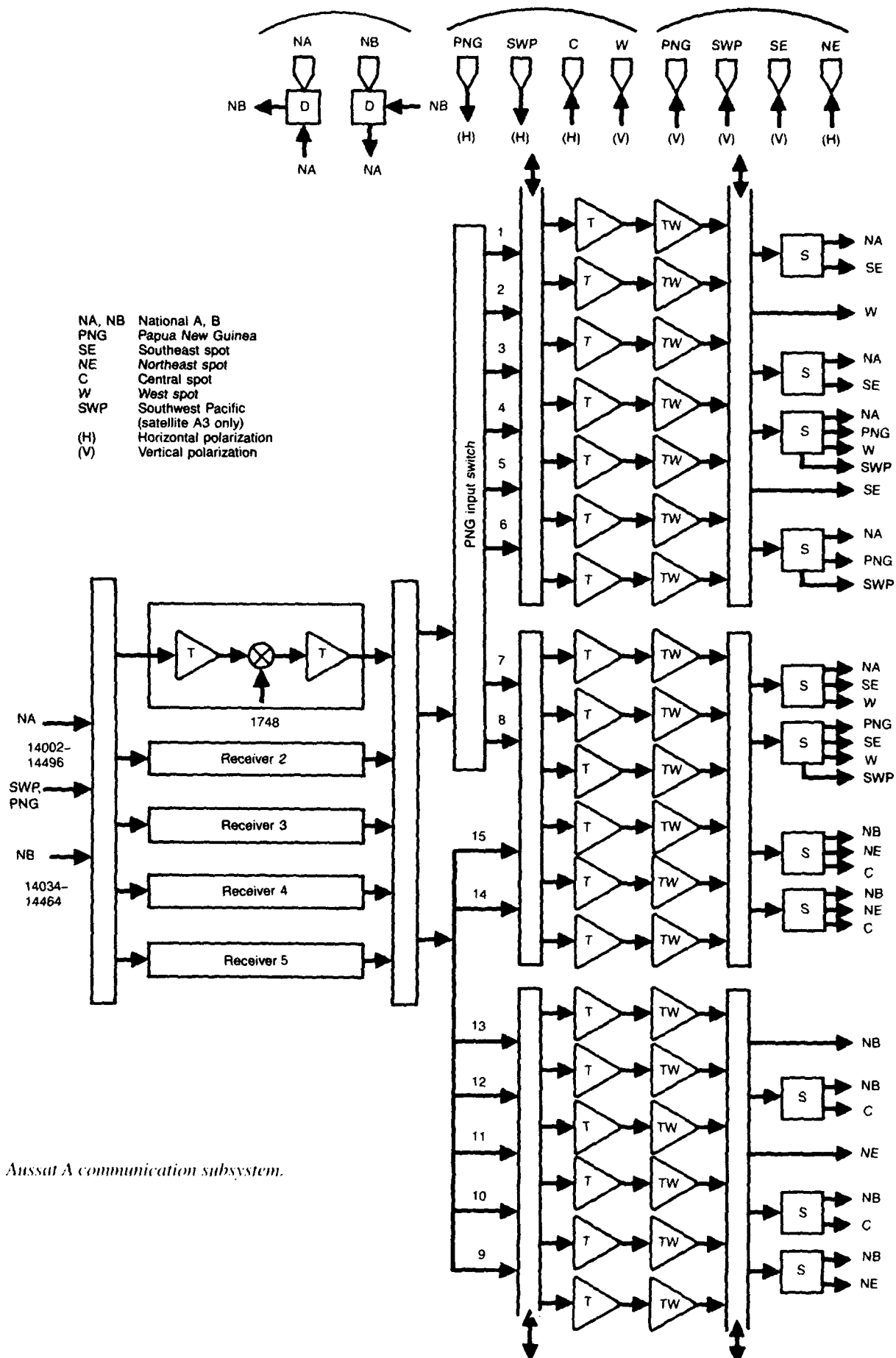
Developed by Hughes Aircraft Company for Aussat Proprietary Ltd., a government corporation

Operated by Aussat Proprietary Ltd.

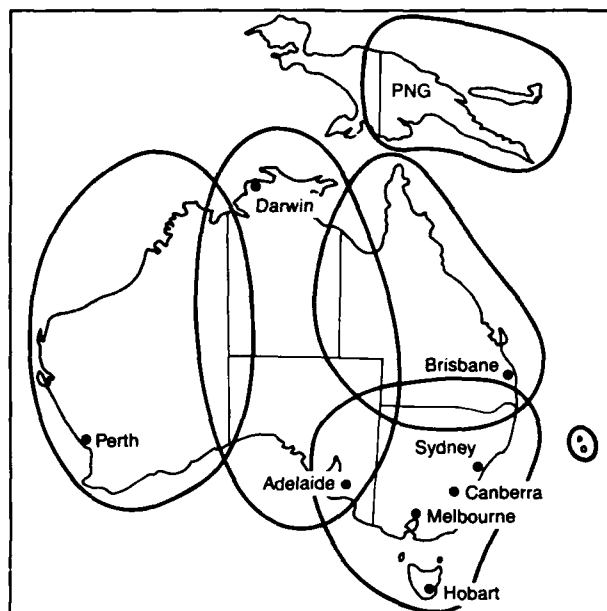
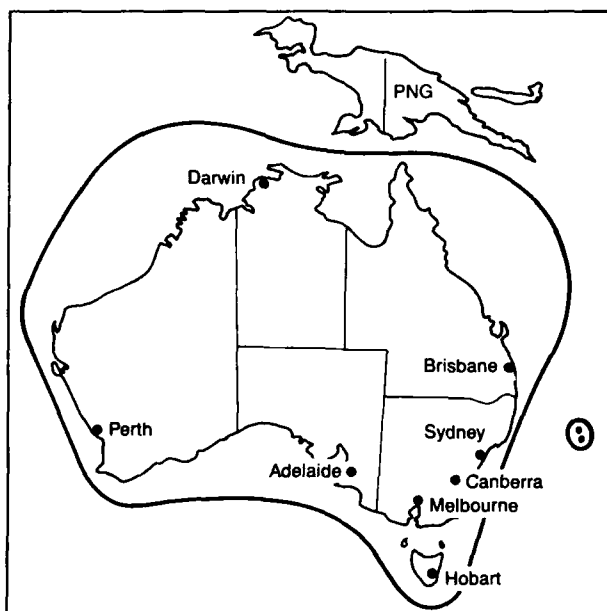
Aussat categorizes their services into television and radio, voice and data, and offshore. The first category is the largest and includes broadcasting to homes, distribution to network stations and closed-circuit TV systems, and transmission of news from remote locations. The voice and data category includes government communications for aeronautical control and other applications, the public telephone network, and business communications. The offshore category is the transponders leased to New Zealand. The transponders connected to the PNG antenna beams were planned

for domestic telephony and broadcasting under the direction of the PNG government. However, they have not been used. Switches and feed horns added to the A3 satellite allow use of these transponders on a southwest Pacific beam. This beam is in use for domestic communications in New Zealand. Technically, it can be used for communications between Australia and New Zealand, but Australia's policy is to use Intelsat for international satellite communications.

The home broadcasting uses the high-power transponders and spot beams. Home receivers with 4- to 5-ft antennas can receive one television and three radio programs. This broadcasting is aimed at the more than one million people who have poor quality or no television service. Aussat has earth terminals in all the major cities for voice and television transmissions. Voice signals are SCPC/CFM for low density and 2 Mbps QPSK for high density. By 1988, about 350 other earth terminals were in use; some are for government communications but more are private terminals for business communications. Antenna sizes vary from 8 to 43 ft.



Aussat A communication subsystem.



About 2000 terminals are used for television reception by organizations, and thousands more are used at homes. All of these earth terminals are built in Australia.

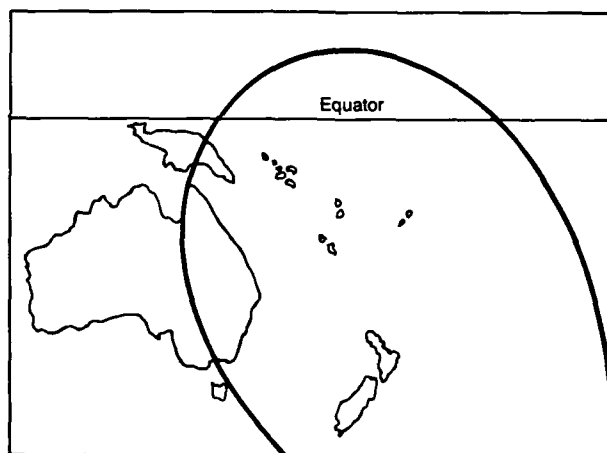
Three satellites were built; two were launched in 1985 and are in use. Their capacity was all assigned before launch due to a surge in demand as the system neared operations. Therefore, Aussat launched the third satellite as soon as possible. Each of these satellites was in use within five weeks after launch. Aussat controls the satellites from an operations center in Sydney through TT&C sites in Sydney and Perth.

Aussat was considering a fourth satellite but turned their planning toward a second-generation system, now Aussat B [16-22]. Discussions with potential contractors began in 1986, and formal proposals were received at the end of 1987. A contractor was selected in June 1988. The contract is for Satellites B1 and B2, delivered in orbit, and some new equipment for the ground control center. They will replace A1 and A2 and are scheduled to be in orbit more than one year before the expected end of life of the earlier satellites. Their ends of life, due to fuel depletion, are estimated to be the end of 1992 and middle of 1993. A third satellite will be required to replace A3 in 1997. It will be either B3, a copy of B1, or C1, the first of a third generation of Aussats.

The Aussat B satellite design is different from Aussat A. The B satellites are three-axis-stabilized with solar arrays and antennas that deploy in orbit. Although three-axis communication satellites are very common, Aussat B is the first three-axis commercial communication satellite from this manufacturer. The primary payload of Aussat B is very similar to that of Aussat A, which will allow an easy transition between the two. Unlike Aussat A, the B satellites have additional payloads: an operational mobile communications payload, a laser retroreflector for precise ranging in support of time synchronization transmissions, and a 28-GHz beacon for propagation studies. Satellite and payload characteristics are:

Satellite

Body $7.5 \times 7.5 \times 7.5$ ft, span of deployed antennas 36.5 ft, span of



Aussat A service areas.

deployed solar arrays 67.5 ft

3670 lb in orbit, beginning of life

Sun-tracking solar arrays and NiH_2 batteries, more than 3200 W at beginning of life

Three-axis-stabilized using double-gimballed momentum wheels

Solid rocket motor for perigee maneuver, liquid bipropellant propulsion for apogee maneuver and on-orbit use

Configuration

Ku: Fifteen 54-MHz bandwidth single-conversion transponders, dual-polarization frequency reuse

L: Two 14-MHz bandwidth transponders, one Ku-band receive and L-band transmit (to mobiles), one L-band receive and Ku-band transmit (from mobiles)

Ka: One beacon

Transmitter

Ku: 12.255 to 12.747 GHz

Two rings of eleven 50-W linearized TWTs each, eight active and three spares (sixteen active TWTAs support the 15 Ku transponders plus the L to Ku transponder)

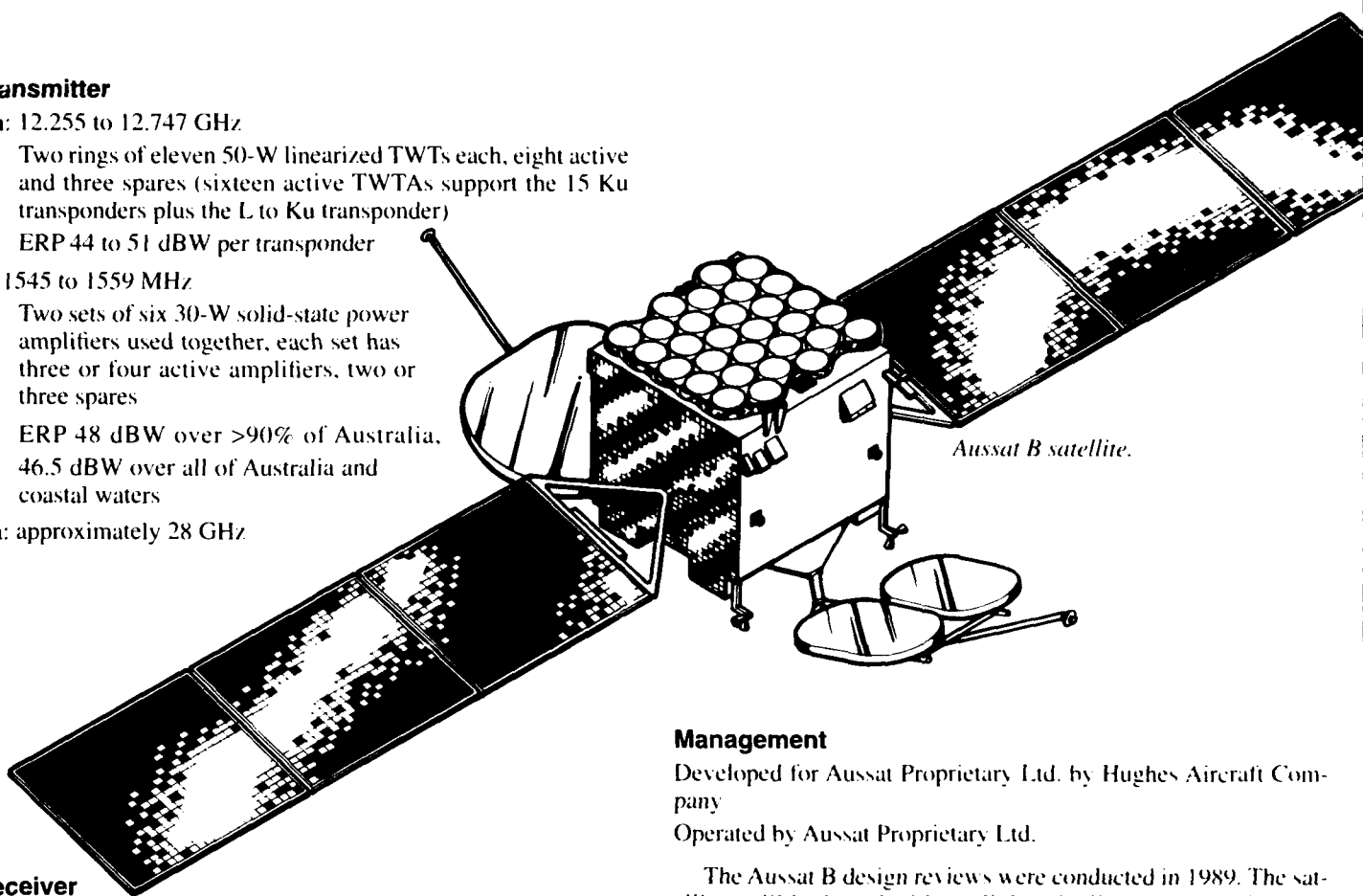
ERP 44 to 51 dBW per transponder

L: 1545 to 1559 MHz

Two sets of six 30-W solid-state power amplifiers used together, each set has three or four active amplifiers, two or three spares

ERP 48 dBW over >90% of Australia, 46.5 dBW over all of Australia and coastal waters

Ka: approximately 28 GHz



Receiver

Ku: 14.003 to 14.495 GHz

Two active and three spare receivers

G/T -3 dB/K minimum

L: 1646.5 to 1660.5 MHz

One active and one spare receiver

G/T +1 dB/K over populated areas, -1.5 dB/K over 90% of Australia

Antenna

Ku: Three offset-fed parabolic reflectors, two approximately 3.5 x 5 ft, one approximately 6 x 7.5 ft; one smaller reflector forms a national and New Zealand receive beam and northeast and southeast transmit beams; the other forms a national receive beam and central and western transmit beams; the larger reflector forms national and New Zealand transmit beams; each reflector uses dual linear polarizations

L: An array of thirty short backfire elements, national coverage transmit and receive beams, circular polarization

Ka: Two horn antennas, one for each linear polarization, national coverage

Design life

Fourteen years

Orbit

Synchronous equatorial, stationkeeping to $\pm 0.05^\circ$ N-S and E-W

Orbital history

B1: launch scheduled March 1992, will go to 160° E longitude

B2: launch scheduled September 1992, will go to 156° E longitude

Long March 2E launch vehicle

Management

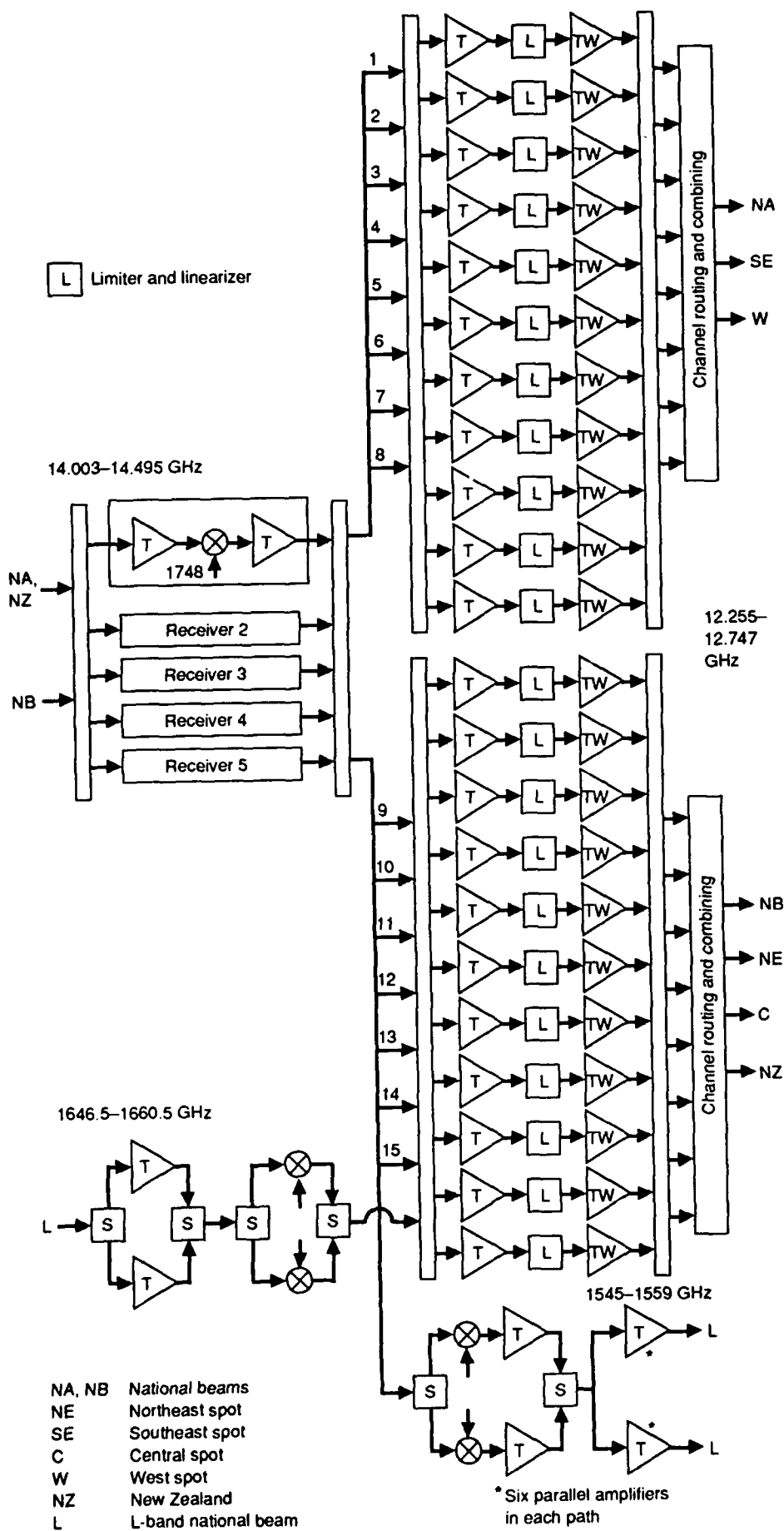
Developed for Aussat Proprietary Ltd. by Hughes Aircraft Company

Operated by Aussat Proprietary Ltd.

The Aussat B design reviews were conducted in 1989. The satellites will be launched into slightly inclined orbits and tested, then moved next to the older satellites. The orbit phasing will cause the inclination to drop to zero about the time of the transfer of services from the old satellites to the new satellites. Aussat will then use B1, B2, and A3 to provide the services described above. A decision on the B3 or C1 satellite will probably occur in 1992, to allow its launch at least one year before the 1997 estimated end of life for A3.

The primary Ku-band Aussat B payload provides fifteen transponders, as does Aussat A. The differences are wider transponder bandwidth, higher transmitter power, national beams weighted to favor the populated parts of the country, and considerable flexibility to serve New Zealand. The satellites can handle international traffic between the two countries, if Australian policy moves away from 100% use of Intelsat. Aussat B has no PNG beam; it has a New Zealand spot beam, but no broad southwest Pacific beam; the four Australian spot beams are the same as those on Aussat A.

The mobile services payload is partially integrated with the primary payload, because it uses Ku-band for links between base stations and satellites. It uses L-band for links between mobile terminals and the satellites. This payload will be used for public and private telephone and data circuits and for short digital messages. Requests and assignments will be made over special signalling channels connecting users to Aussat's Network Management Center. The short messages will be sent over the signalling channel. Digital data will be transmitted QPSK at 2400 bps and voice using 4800 bps encoded to 6400 bps QPSK or analog companded single sideband. Base stations will be either private or multiuser sites operated by Aussat. Mobile terminals will be of several types for voice, data, or messages. Aussat mobile services are scheduled to begin shortly after the launch and checkout of Aussat B1.



Aussat B communication subsystem.

* * * * *

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THAILAND

Thailand has used leased capacity on the Indonesian Palapa system for domestic communications since 1979. In June 1991, Thailand awarded a contract for two satellites and a ground con-

trol station. The satellites will be relatively small, each having ten C-band transponders with 8-W amplifiers and two Ku-band transponders with 50-W amplifiers. The first launch could be in 1994.

OTHER SATELLITES

There are several satellites that do not fall into any of the previous categories. Some of these systems do not compare with the other programs in terms of expenditure or communication capacity, but they illustrate the variety of applications found for satellite communications. Of particular note are the Oscar satellites developed by amateur radio operators. Although these are physically small, they are the product of international cooperation, and they have been used by over 10,000 people in more than 100

countries. Another group are the meteorological satellites, which include transponders for relaying data from many unattended data collection platforms to a central site. A third type of satellite has a payload that consists of one or more beacon transmitters. These satellites can be used by a system operator to gain experience in satellite development and/or operations, to check ground control networks, or as sources for propagation studies.

SATELLITES FOR RADIO AMATEURS and EDUCATION

Oscar (Amsat and Universities)

Oscar (Orbiting Satellite Carrying Amateur Radio) is a space project of amateur radio operators [1-31]. The Oscar project was started in 1960 by amateurs in California, most of whom were professionally involved in space technology activities. The Oscar satellites are launched as secondary payloads occupying excess, and otherwise unused, launch vehicle capability. The technical sophistication and human participation in Oscar-related projects have grown substantially over the past three decades. Table 1 is a summary of all the Oscars launched through 1990. (These satellites have no relation to a series of United States Navy navigation satellites also named Oscar.)

The first two satellites, Oscar 1 and 2, were launched in December 1961 and June 1962. These satellites transmitted beacon signals with simple modulation. Each weighed about 10 lb and operated about 400 hr.

Oscar 3 was the first amateur communication satellite. The satellite repeater had a 50-kHz bandwidth operating in the 144- to 146-MHz band. This satellite operated more than two weeks until the battery was depleted. A number of two-way links were established by radio operators in the United States, Canada, and Europe. One-way transatlantic links were established twice. Oscar 4 also had a communications repeater with a 10-kHz bandwidth. However, because of a launch vehicle failure, the desired orbit was not achieved, and only a few two-way contacts were established. However, one of these was the first direct satellite link between the United States and the Soviet Union. These four satellites form the first phase of amateur satellite work.

In 1969, the Radio Amateur Satellite Corporation (Amsat) was formed to continue the Oscar project and expand it to international participation. Oscar 5 was a beacon satellite prepared by amateurs in Australia. It was the first Oscar to have a command subsystem, an important step toward long-life, complex satellites. This satellite and Oscars 6, 7, and 8 were the second phase of amateur satellites, characterized by multiyear lives in low orbits.

Oscars 6 through 8 all had command subsystems and were powered by solar arrays coupled with rechargeable NiCd batteries. They used magnets to provide two-axis stabilization, aligning the spacecraft axis with the local geomagnetic field. Portions of these satellites were built in the United States, Australia, West Germany, Canada, and Japan. They were assembled in the United States. Although almost all the labor was done by amateurs, many hardware items were donated by government and industrial organizations. The design lives of these three satellites were one, three, and three years, but each operated about five years.

Oscar 6 had a communication repeater with a 100-kHz bandwidth; it received at 146 MHz and transmitted at 29.5 MHz. Oscar 7 had two repeaters. One was the same as Oscar 6 except for a slight frequency change and increased output power. The other received at 432 MHz and transmitted at 146 MHz. An onboard timer automatically switched from one repeater to the other every 24 hr. This timer was part of the control circuitry that automatically switched one repeater on in a low power mode when the battery was discharged to a certain point. On several occasions, these two satellites were used together with a 432-MHz uplink to Oscar 7, a 146-MHz intersatellite link, and a 29-MHz downlink from Oscar 6. Oscar 8 also had two repeaters. One was the same as Oscar 7, operating at 146/29 MHz. The other received at 146 MHz and transmitted at 435 MHz. Only one repeater was on at a time.

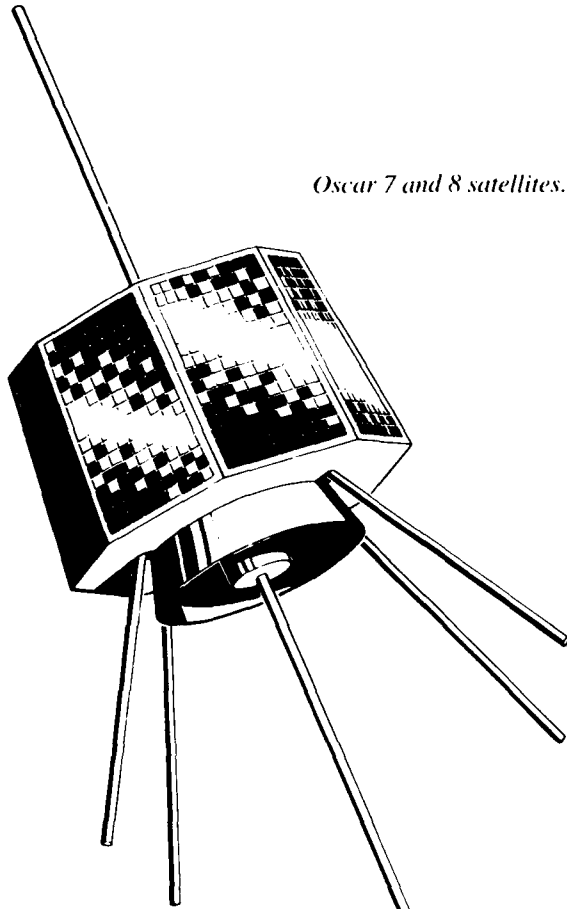
Oscar 9, or UoSAT 1, was the first satellite built by the University of Surrey, England. The goal of UoSAT 1, and the continuing purpose of the UoSAT program, is to demonstrate the development of low-cost sophisticated satellites and to use these satellites to promote space science and engineering in education. The smallness and sophistication of the UoSATs centers on the use of microelectronic technology. The application of UoSATs to education broadens the role of Oscars beyond amateur communications and involves direct contact with the satellites from simple ground terminals at schools of all levels.

UoSAT 1 transmitted telemetry and experiment data on 146- and 435-MHz beacons. Beacons for propagation research were at 7, 14, 21, and 29.5 MHz and 2.4 and 10.4 GHz. Transmitter powers were 100 to several hundred milliwatts. Other experiments were a magnetometer, two particle counters, a CCD camera with 256 x 256 elements, and a speech synthesizer. The camera and two microwave antennas were mounted on the earth-viewing side. High-frequency antennas extended from several parts of the body. The magnetometer was deployed on a gravity-gradient stabilization boom on the anti-earth end of the body. Solar cells on the four sides of the body, plus nickel cadmium batteries, provided an average power of about 25 W.

Oscar 9 was launched in October 1981. Although initial operations were difficult, the University considered the time a good learning experience. In the following years, the satellite continued to operate at full capacity and did so until it reentered the earth's atmosphere in October 1989.

Oscar 10 is the beginning of a phase of amateur communication satellites characterized by long-life and high-altitude orbits.

Oscar 7 and 8 satellites.



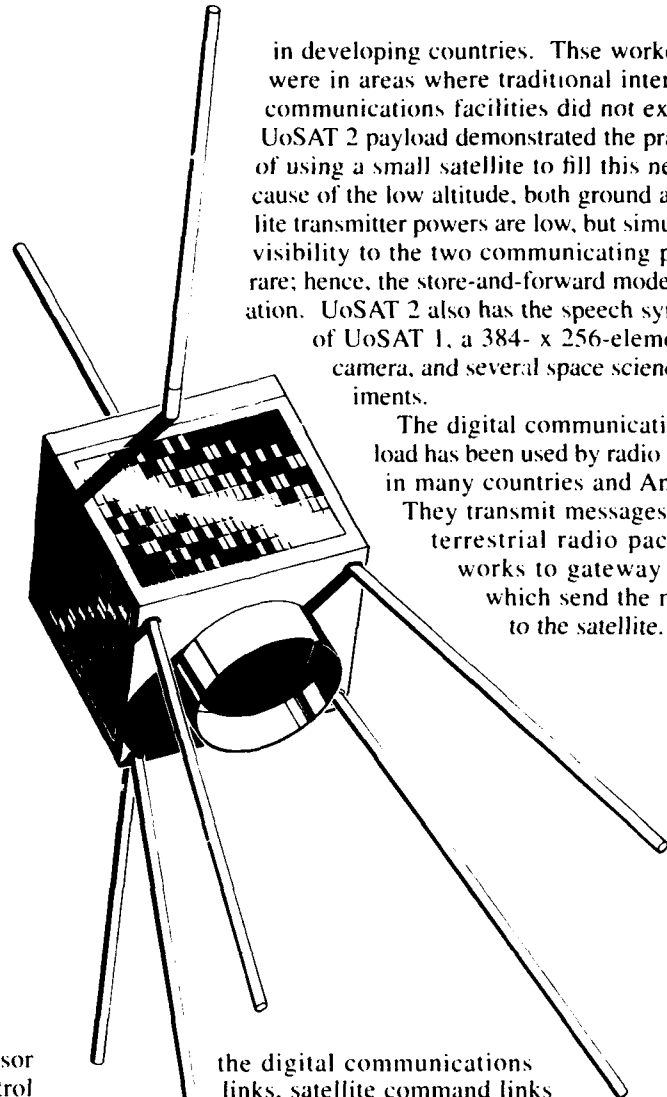
The satellite is shaped like a three-pointed star. It is spin-stabilized and has magnetic torquers to control the spin orientation. The spin axis is oriented so that, at apogee, the antennas point toward the center of the earth. A microprocessor monitors telemetry and has a considerable autonomous control capability. All electronics are mounted in the arms of the satellite. A motor located in the center of the satellite is used to raise its orbital apogee and inclination. The objective of the selected orbit is to provide long-duration coverage to the largest possible number of amateur radio operators. The satellite has two repeaters. One uses the 435/146-MHz combination used before. The other is the first amateur use of a higher uplink frequency (1269 MHz), coupled with a 435-MHz downlink.

The West German Amsat organization has the central role in Oscar 10. It received support and equipment from several European countries and the United States. Their first satellite, sometimes called Oscar 9, was destroyed by a launch vehicle malfunction in 1980. Oscar 10 was launched in June 1983. It encountered some difficulties which resulted in a less than optimum orbit. The use of the satellite for communications started in August 1983. The orbit of Oscar 10 causes the satellite to be in regions of high radiation for many hours per day. This radiation caused failures of the satellite's solid-state memory device after a few years. By 1990, altitude control capabilities declined, but the satellite was still useful for communications.

Oscar 11 is UoSAT 2. Mechanically, and in appearance, it is very similar to UoSAT 1. The primary payload is for digital store-and-forward communications. The motivation for this payload came from Volunteers in Technical Assistance, a United States organization providing technical support to field workers

in developing countries. These workers often were in areas where traditional international communications facilities did not exist. The UoSAT 2 payload demonstrated the practicality of using a small satellite to fill this need. Because of the low altitude, both ground and satellite transmitter powers are low, but simultaneous visibility to the two communicating parties is rare; hence, the store-and-forward mode of operation. UoSAT 2 also has the speech synthesizer of UoSAT 1, a 384- x 256-element CCD camera, and several space science experiments.

The digital communications payload has been used by radio amateurs in many countries and Antarctica. They transmit messages through terrestrial radio packet networks to gateway stations which send the messages to the satellite. Besides



the digital communications links, satellite command links exist at 144, 437, and 1268 MHz.

Telemetry can be transmitted at 145.8, 435.0, and 2401 MHz.

UoSAT 2 was built in less than six months, which was the time between NASA's announcement of a secondary satellite launch opportunity and the launch date. UoSAT was launched in

March 1984 to an altitude of about 380 nmi. Like UoSAT 1, there were early problems with satellite control; but subsequently, the satellite performed well. At the end of 1990, it was still in good health and being used regularly.

Oscar 12 is the first Japanese amateur satellite. Its original name was Japanese Amateur Satellite (JAS) 1, but it was renamed Fuji after launch. Hence, it is also Fuji-Oscar 12 or FO 12. It weighs 110 lb and has a communications payload with two modes. One is a nonprocessing repeater with a 100-kHz bandwidth; the uplink is at 146 MHz and the downlink at 436 MHz. The other mode is a digital processing repeater with four fixed uplink and downlink frequencies in the same bands as the other repeater. Only one mode is active at a time. Fuji was launched in August 1986 on the first test flight of the Japanese H-1 launch vehicle. It was still operating in 1990.

Oscar 13 is another German Amsat project, similar in design and orbit to Oscar 10. It is also known as Amsat-Oscar 13 or AO 13. It has a communications payload which operates in four

Table 1. Oscar Summary

NAME	SHAPE, SIZE, in.	WEIGHT, lb	PRIMARY PAYLOAD	FREQUENCY BANDS ^a	LAUNCH DATE	STATUS
Oscar 1	Rectangular, 6 x 12 x 12	10	Beacon	VHF	12 Dec 1961	Operated 18 days
Oscar 2	Rectangular, 6 x 12 x 12	10	Beacon	VHF	1 Jun 1962	Operated 18 days
Oscar 3	Rectangular, 7 x 12 x 17	33	Repeater	VHF	9 Mar 1965	Operated 16 days
Oscar 4	Tetrahedron, 19 on a side	29	Repeater	VHF, UHF	21 Dec 1965	Operated 3 months
Oscar 5	Rectangular, 6 x 12 x 17	39	Beacons	10 m, VHF	23 Jan 1970	Operated 2 months
Oscar 6	Rectangular, 6 x 12 x 17	40	Repeater	10 m, VHF	17 Oct 1972	Turned off June 1977
Oscar 7	Octagonal cylinder, 17 x 17	65	Repeaters	10 m, VHF, UHF	15 Nov 1974	Operated until mid-1981
Oscar 8	Cube, 18	60	Repeaters	10 m, VHF, UHF	5 Mar 1978	Operated until 1983
UoSAT 1 (A), Oscar 9	Rectangular, 17 x 17 x 29	~110	Science and education experiments	See text	6 Oct 1981	Operated 8 years
Oscar 10	Three arm star, 17 high x 50 span	~200	Repeaters	VHF, UHF, L	16 Jun 1983	In use (1990)
UoSAT 2 (B), Oscar 11	Rectangular, 14 x 14 x 23	~110	Digital store and forward	VHF, UHF	1 Mar 1984	In use
Fuji 1, Oscar 12	26 side polyhedron, 18 diam	110	Repeater	VHF, UHF	12 Aug 1986	In use
Oscar 13	Three arm star, 17 high x 50 span	~200	Repeaters	VHF, UHF, L, S	15 Jun 1988	In use
UoSAT 3 (D), Oscar 14	Rectangular, 14 x 14 x 24	100	Digital store and forward	VHF, UHF	21 Jan 1990	In use
UoSAT 4 (E), Oscar 15	Rectangular, 14 x 14 x 24	100	Technology experiments	VHF, UHF	21 Jan 1990	Transmitters failed after 1 day
Oscar 16	Cube, 9	22	Digital store and forward	VHF, UHF, S	21 Jan 1990	In use
DOVE, Oscar 17	Cube, 9	22	Digital store and forward, digital voice	VHF, UHF, S	21 Jan 1990	In use
Webersat, Oscar 18	Rectangular, 9 x 9 x 12	27	Digital store and forward, video experiments	VHF, UHF	21 Jan 1990	In use
Oscar 19	Cube, 9	22	Digital store and forward	VHF, UHF	21 Jan 1990	In use
Fuji 2, Oscar 20	26 side polyhedron, 18 diam	110	Repeater	VHF, UHF	7 Feb 1990	In use

^a10 m is approximately 29.5 MHz, VHF is 144 to 146 MHz, UHF is 435 to 436 MHz (432 MHz on early satellites), L-band is approximately 1269 MHz, S-band is 2400 to 2401 MHz.

different modes. All of these modes are nonprocessing repeaters; the differences are the frequencies and include increased use of microwaves. The uplink and downlink frequency combinations are approximately 435 and 146 MHz with 150-kHz bandwidth, 1269 and 436 MHz with 290-kHz bandwidth, 144 and 436 MHz with 50-kHz bandwidth, and 436 and 2401 MHz with 36-kHz bandwidth.

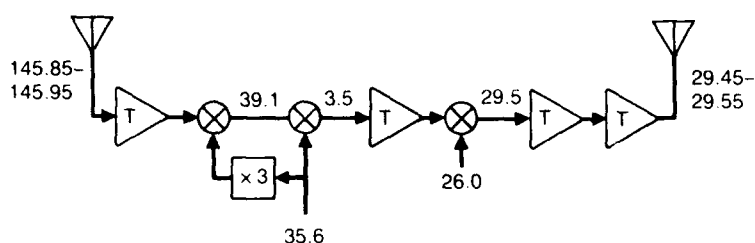
Oscar 13 was launched in June 1988 and is in use. The end of its life will be caused by lunar and solar perturbations of its orbit causing atmospheric drag to increase. The predicted end of life is 1997, or perhaps a few years earlier.

Oscars 14 through 19 were launched together in January 1990, all mounted on the secondary payload platform of an Ariane

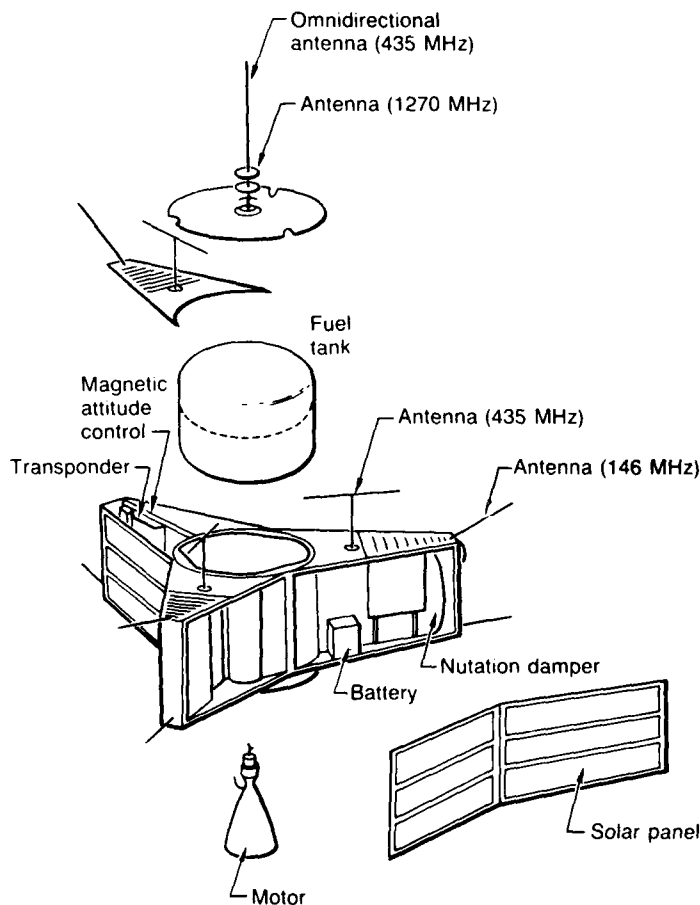
launch vehicle. These six satellites are of two designs, one for Oscars 14 and 15 and the other design for the other four satellites.

Oscars 14 and 15, or UO 14 and UO 15, are UoSATs 3 and 4. Prior to launch, they were UoSATs D and E. These two satellites took over the missions and payloads of UoSAT C, whose launch opportunity was eliminated by NASA launch schedule changes. Since the Ariane launch required smaller satellites, two satellites were used to replace one.

Oscars 14 and 15 are rectangular boxes about 14 in. square and 24 in. tall. Each weighs 100 lb and has a 20-ft boom which deploys from the top surface to provide gravity-gradient stabilization. Oscar 14's primary payload is for digital store-and-forward communications, an advancement from the similar payload on Oscar 11. The uplink is at 146 MHz, the downlink at 435 MHz.



Oscar 6 through 8 146/29-MHz communication subsystem.



Oscar 10 satellite details.

This payload has 4 Mbytes of memory, in contrast to only 128 kbytes on Oscar 11.

Oscar 15 is a technology demonstration satellite. It has a parallel computing experiment, samples of new GaAs, InP, and silicon solar cells from several manufacturers, and a CCD camera. Both satellites have radiation measurement sensors.

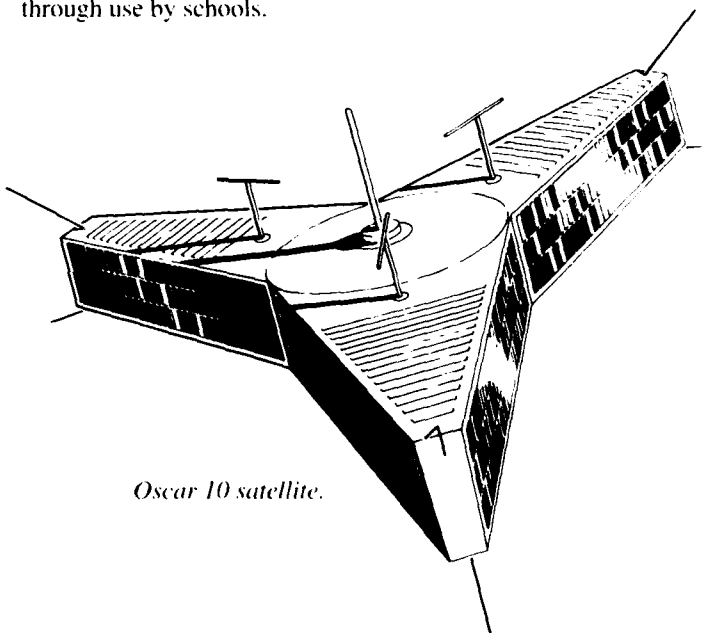
Oscar 14 is actively used, but Oscar 15's transmitters have not been on since the end of the first day in orbit. The cause has not been determined; but it is not a general satellite failure, because radiation from the satellite receiver's local oscillator has been detected by a ground station with a large antenna and sophisticated processing.

Oscars 16 through 19 are rectangular boxes 9 in. square. Three are 9 in. tall; Oscar 18 is 12 in. tall. The three weigh 22 lb each, and Oscar 18 weighs 27 lb. The satellite components are mounted on boards which are supported in metal frames. These frames, when bolted together, are the main structure of the satel-

lite, as shown in the figure. Solar cells are placed on fixed sides of this structure. The single antenna on the top is for 146 MHz; the four elements on the bottom are the 437-MHz antenna.

Oscars 16, 17, and 19 were built by Amsat and Oscar 18 by Weber State College in Utah. All four satellites have the same design and same subsystems, except for payloads. All four have a digital store-and-forward payload with a 146-MHz uplink and 437-MHz downlink. The memory size is 8 Mbytes; data rates are 1200 and 4800 bps. The transmitter power is varied by the satellite computer to match the power available on the satellite. Maximum power is 4 to 5 W. Oscar 16, AO 16, or Pacsat, also has a 2401-MHz downlink for transmission of the store-and-forward packet messages. Oscar 17 is called DOVE (Digital Orbiting Voice Experiment) or DO 17 because of its digital voice synthesizer. Oscar 18, Webersat or WO 18, has several video experiments including a CCD camera and a CCD spectrometer. Oscar 19 has an additional telemetry subsystem and transmitter as its unique payload. This subsystem was built by radio amateurs in Argentina and is the first spare hardware from that country.

All four satellites have been working properly since launch. Oscars 16 and 19 are primarily for amateur communications, while the other two are aimed at promoting scientific education through use by schools.



Oscar 10 satellite.

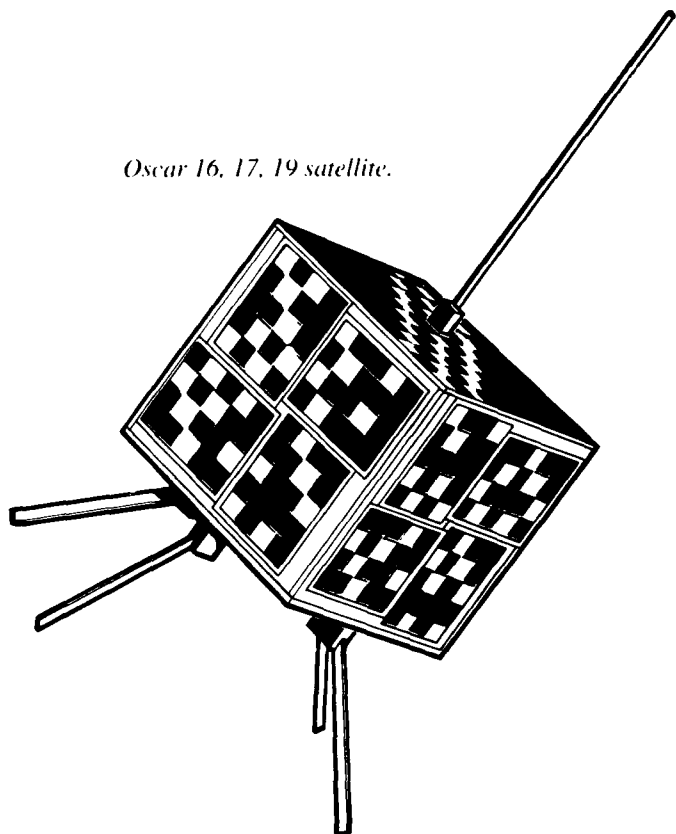
Oscar 20 is Fuji 2, or FO 20. It was originally built as a back-up for Oscar 12 and designated JAS-1b. Since the launch of Oscar 12, experience with that satellite was used to redesign portions of the second satellite. Like Oscar 12, it is a nearly spherical 26-sided structure with a diameter of about 18 in. and a weight of 110 lb.

Oscar 20 has the same processing and nonprocessing modes as Oscar 12 with almost identical frequencies. It was launched in February 1980 and is in use.

UoSAT 5 (F prior to launch) was launched in July 1991. It is a replacement for, and has the same design as, UoSAT 4 (Oscar 15).

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Oscar 16, 17, 19 satellite.



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RS and Iskra

RS is the designation for amateur radio communication satellites developed in the Soviet Union [1-7]. The original RS announcement was made in 1977. At the end of October 1978, two satellites were launched into a near-polar orbit with an altitude of about 900 nmi. After launch, the Soviet Union referred to these satellites as Radio 1 and 2. A set of six satellites, named Radio 3 through 8, were launched together in December 1978. Their orbit is similar to that used for the first two satellites. Three were still operating at the end of 1984.

RS 10 and 11 are modules attached to the Soviet satellite Cosmos 1861, launched in June 1987. Likewise, RS 12 and 13 are on Cosmos 2123, launched in February 1991. RS 14 is on a Soviet civilian satellite launched in January 1991.

The first RS satellites had repeaters with uplinks near 146 MHz and downlinks near 29 MHz. RS 10 and 11 have multiple repeaters using frequencies near 21, 29, and 146 MHz. More than one can be on, to allow two uplink bands with one downlink or vice versa. RS 14 has two repeaters with 435-MHz uplinks and 146-MHz downlinks. Some of the RS satellites also have a subsystem called robot. When the robot receives a Morse Code call sign, it transmits it with the satellite's call sign and stores a record of the contract for transmission to a central ground station.

Three Iskra or Iskara (Spark) satellites also have been announced to be for amateur radio communications. No description

has been given. The first was launched in July 1981. The others were deployed from the Salyut 7 space station in May and November 1982. Because of their low orbits, each reentered the atmosphere within two months.

* * * * *

1. M. N. Sweeting, "The Amateur Space Program," *Journal of the British Interplanetary Society*, Vol. 32, No. 10 (October 1979).
2. A. C. Gee, "Oscar: Amateur Radio Satellites and Spacecraft," *Space Education*, Vol. 1, No. 4 (September 1982).
3. J. M. Henry, "Oscar Satellites. Amateur Radio in Space," Paper 6.7, *First Canadian Domestic and International Satellite Communication Conference* (June 1983).
4. A. C. Gee, "Amateur Radio Satellites," *Space Education*, Vol. 1, No. 8 (October 1984).
5. A. C. Gee, "Amateur Radio Satellite Update," *Space Education*, Vol. 1, No. 9 (May 1985).
6. "Radio Amateurs," *Telecommunication Journal*, Vol. 44, No. 12 (December 1977).
7. *Aviation Week & Space Technology* (6 June 1977), p. 41; (8 August 1977), p. 22; (6 November 1978), p. 22; (24 May 1982), p. 20.

Badr

In July 1990, a Pakistani satellite, Badr, was launched by China. The 110-lb satellite was built by a government research agency with cooperation from the Pakistan Amateur Radio Society. The purposes of the satellite were to test Pakistani-built satellite equipment, demonstrate satellite communications, and gain experience

in satellite operations. The satellite had a digital store and forward communications payload, similar to the one on Oscar 11, UoSAT 2. The satellite transmitter frequencies were near 144 and 146 MHz. The satellite orbit had a very low perigee, and atmospheric drag ended the satellite's life in December 1990.

ORBIS

ORBIS (Orbiting Radio Beacon Ionospheric Satellite) was a project of the Air Force Cambridge Research Laboratories [1, 2]. After one launch failure, an ORBIS was put into a low orbit in November 1964. It transmitted on 10.004 MHz for about two weeks, until it reentered the atmosphere. The primary purpose of ORBIS was a study of ionospheric ducting. The program was later split into ORBIS Low and ORBIS High, with low and high referring to satellite altitude.

Satellite OV2-5 carried eleven experiments, one of which was an ORBIS High transmitter. OV2-5 was launched into a synchronous altitude orbit in September 1968. Satellite OV4-3 carried three experiments, one of which was an ORBIS Low transmitter. The OV4-3 was launched in November 1966 with OV4-1. It op-

erated for one month and reentered the atmosphere in January 1967.

ORBISCAL (ORBIS Calibration), also called OV1-17A, had two transmitters, at 8.98 and 13.25 MHz. It operated for one week between launch and reentry in March 1969.

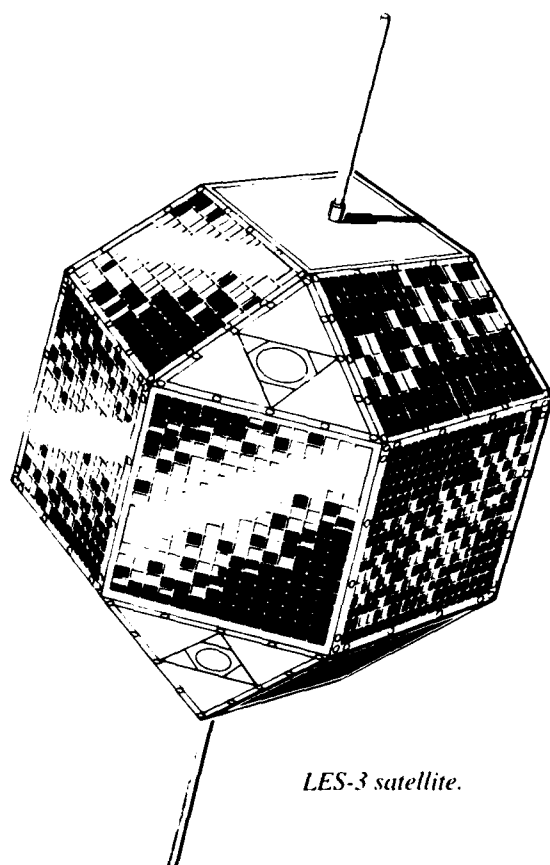
* * * * *

1. J. P. Mullen and R. S. Allen, "Synoptic Data from the ORBIS Experiment," *Radio Science*, Vol. 1 (New Series), No. 10 (1966).
2. J. W. Powell and G. R. Richards, "The Orbiting Vehicle Series of Satellites," *Journal of the British Interplanetary Society*, Vol. 40, No. 9 (September 1987).

LES-3

The third Lincoln Experimental Satellite (LES-3) payload was a beacon whose output was used for propagation measurements [1, 2]. The phenomenon of most interest was multipath. The beacon frequency was 232.9 MHz, which is in the range of frequen-

cies (approximately 230 to 280 MHz) used by many military communication satellites that followed LES-3. The beacon was modulated by a 15-bit sequence from a four-stage pseudorandom source. The modulation rate was 100 kbps. The modulated signal was amplified and equally split to two monopole antennas.



LES-3 satellite.

The LES-3 satellite is similar to LES-1 and -2 except for the payload. The body has eighteen square and eight triangular faces. The antennas are mounted to the center of two opposite square faces. Solar cells are mounted on the square faces. The satellite had no battery and no command and telemetry. The beacon was activated automatically at orbital insertion. The satellite details are as follows:

Satellite

26-sided polyhedron, 2-ft dia., 4 ft between ends of antennas
34 lb in orbit
Solar cells, no batteries, 25 W maximum at beginning of life
Spin-stabilized, approximately 140 rpm

Configuration

One beacon transmitter

Transmitter

232.9 MHz, 100-kHz biphase modulation, 10-W power output, 15-dBW maximum ERP

Antenna

Two quarter-wave monopoles, extending from opposite faces of the satellite body, toroidal pattern

Design Life

One year

Orbit

Subsynchronous equatorial, approximately 18,200-nmi altitude intended; 105 × 18,200 nmi, 26-deg inclination actual

Orbital history

Launched 21 December 1965

Operated more than one year

Decayed 6 April 1968

Titan III-C launch vehicle (shared with other satellites)

Management

Developed by MIT Lincoln Laboratory

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1. H. Sherman, et al., "The Lincoln Experimental Satellite Program (LES-1, -2, -3, -4)," *Journal of Spacecraft and Rockets*, Vol. 4, No. 11 (November 1967).
2. H. Sherman, et al., "The Lincoln Experimental Satellite Program (LES-1, -2, -3, -4)," Paper 66-271, *AIAA Communications Satellite Systems Conference* (May 1966).

OV4-1

The OV4-1 experiment [1-3] is of historical interest, as it was the first satellite-to-satellite crosslink. Beginning in 1948, communication between near-antipodal points on the earth had been demonstrated at frequencies well above what was expected, based on traditional understanding of HF propagation. Then, when the space age began, there were many reports of ground-based reception of HF or VHF transmissions from satellites far beyond the horizon. Various modes of ionospheric propagation were suggested to explain these phenomena.

The OV4-1 experiment was developed to extend the investigations of ionospheric propagation. A secondary purpose was to determine the feasibility of communication beyond the line of sight between two low-altitude satellites. A number of Air Force experimental satellites that were flown in the 1960s were designated OV, or orbiting vehicles. The OV4 was the fourth basic type of OV. The OV4-1T and OV4-1R were separate satellites, which were the transmitting and receiving portions, respectively, of the link. The OV4-1R also had a telemetry transmitter. The OV4-2 was a copy of OV4-1, but the satellites were never launched.

The OV4-1 satellites were launched together into the same orbit and were then given a slight relative velocity, so that their separation varied from zero to antipodal. These satellites were launched in early November 1966 and operated until the end of that year. The OV4-1T operated continuously, but the OV4-1R operated only by command when it was in sight of a ground terminal equipped to receive and record the experiment telemetry. About thirty telemetry records were gathered, indicating successful operation at ranges varying from a few hundred miles to antipodal distance. Other experiment details are as follows:

Satellite

OV4-1T: cylinder with one domed end, 17-in. dia., 45 in. long

OV4-1R: cylinder with one domed end, 17-in. dia., 37 in. long

240 lb (T), 300 lb (R)

Silver oxide-zinc batteries, 7.9 kWh

No stabilization

Transmitter

20.75, 34.3, and 46.8 MHz

20-, 100-, and 1000-msec pulse widths

2-, 100-, and 1000-W peak power levels

Receiver

20.75, 34.3, and 46.8 MHz

Antenna

Dipole with linear polarization on each satellite

Orbit

150- to 160-nmi altitude, 33-deg inclination

Orbital history

Launched 3 November 1966

Operated until 30 December 1966

Decayed in January 1967

Management

Developed by Raytheon for the United States Air Force

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1. J. I. Barker and M. D. Grossi, "Design of a Satellite-to-Satellite Communications Experiment to Explore HF/VHF Guided Propagation in the Lower Ionosphere," *Radio Science*, Vol. 1 (New Series), No. 10 (October 1966).
2. "Spacecraft Details," *TRW Space Log*, Vol. 6, No. 4 (Winter 1966-67).
3. J. W. Powell and G. R. Richards, "The Orbiting Vehicle Series of Satellites," *Journal of the British Interplanetary Society*, Vol. 40, No. 9 (September 1987).

TEST AND TRAINING SATELLITES

The Test and Training Satellites (TETR or TTS) [1, 2] were developed by NASA for use during exercises of the Manned Spaceflight Network. Their primary purpose was to simulate the downlink of an Apollo spacecraft for network checkout prior to an Apollo flight. The TTS performed the simulation by retransmitting a sample downlink signal that it had received from a ground station. This signal could include ranging, telemetry, voice, and biomedical data. Four of these satellites were launched as secondary payloads. The satellite details are as follows:

Satellite

Octahedron, 12 in. on a side

40 to 45 lb in orbit

Solar cells and battery, 4 to 5 W

Magnetic stabilization

Transmitter

2282.5 MHz, 0.8-W output

Receiver

2101.8 MHz

Antenna

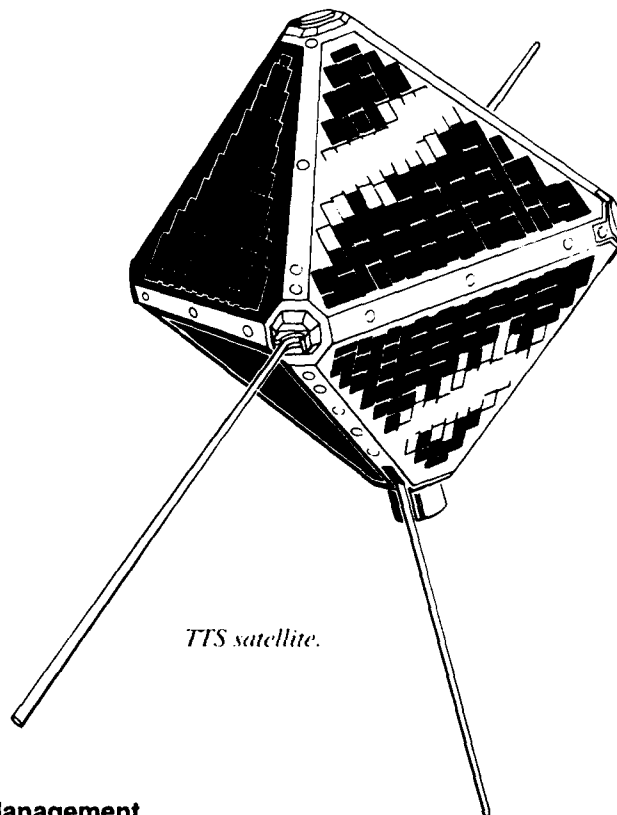
Monopole for reception, dipole for transmission

Design life

Seven months

Orbital history

- 1: launched 13 December 1967, 158 x 261 nmi, 33-deg inclination
- 2: launched 8 November 1968, 202 x 510 nmi, 33-deg inclination
- 3: launched 27 August 1969, launch vehicle failure
- 4: launched 29 September 1971, 215 x 329 nmi, 33-deg inclination

**Management**

Developed by TRW for NASA

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1. "Spacecraft Details," *TRW Space Log*, Vol. 7, No. 4 (Winter 1967-68); Vol. 8, No. 4 (Winter 1968-69); Vol. 9, No. 4 (Winter 1969-70); Vol. 10 (1972).
2. "Satellite Digest," *Spaceflight*, Vol. 14, No. 3 (March 1972).

EOLE

Eole was a satellite developed by the French national space agency for communication with and data collection from remote

balloon-borne meteorological sensors [1-3]. It was a cooperative program with NASA called CAS-A. Peole (Preparation for Eole)

as an experimental satellite with a similar payload. The basic mission of Eole was to interrogate the sensors and to relay data on them to a ground station. During the first five months after Eole was launched, 500 weather balloons were released from Argentina. Eole relayed pressure and temperature data from them to station in France. Eole also was used to determine the location of the balloons to provide data on wind velocity.

Eole was gravity-gradient-stabilized, with antennas on the end, that was oriented toward the earth. Solar cells were mounted both on the satellite body and on panels, which were deployed in orbit. Eole had two communication subsystems: one operated at 401 and 464 MHz for links with sensor platforms, and the other used 136 and 148 MHz for links with ground terminals. The satellite had an onboard memory so that it could collect sensor data even when it was not in sight of a ground terminal. The links between Eole and the sensor platforms were designed so that the satellite could collect data on the link range and range rate. On the ground, this information was used to compute the sensor platform location. The satellite details are as follows:

satellite

Octagonal cylinder, 28-in. dia., 21.5-in. height, approximately 46 in. overall height excluding gravity-gradient boom

86 lb in orbit

solar cells

gravity-gradient stabilization

transmitter

64 MHz (interrogation of sensors), 4-W output, 48 bps

36.35 MHz (to ground station), 250-mW output, 1536 bps

receiver

401 MHz (from sensors), 48 bps

48.25 MHz (from ground station)

antenna

Conical spiral for 401 and 464 MHz

Turnstile for 136 and 148 MHz

Onboard storage

Ferrite core memory

1192 sixteen-bit words

Design life

Six months

Orbit

Eole: 270 x 386 nmi, 15-deg inclination

Eole: 365 x 478 nmi, 50-deg inclination

Orbital history

Eole: launched 12 December 1970

Eole: launched 16 August 1971, operated more than two years

NASA Scout launch vehicle

Management

Developed by Laboratoire Central de Telecommunications (France) for CNES (French national space agency)

Eole was launched in August 1971 by a NASA Scout vehicle. Although the design life was six months, it operated over two years. Following the initial balloon experiments, Eole was used



Eole satellite.

to relay data from a variety of other sensor platforms. The Eole mission was followed by the Argos data collection package built by France and flown on the United States NOAA meteorological satellites in low-altitude polar orbits. The most recent Argos is on NOAA 11, launched in September 1988.

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1. L. Mirabel and G. Cardona, "Eole Satellite: Weather Balloon Location and Data Collection System," *Electrical Communication*, Vol. 47, No. 1 (1972).
2. *Flight International* (26 August 1971), p. 343.
3. "Spacecraft Details," *TRW Space Log*, Vol. 10 (1972).

GOES

The Geostationary Operational Environmental Satellites' (GOES) primary mission is to gather and disseminate data concerning the earth's surface and atmosphere [1-3]. To accomplish this mission, the satellites are equipped to perform three functions. The first is making visible and infrared measurements of

the surface and atmosphere and transmitting these data to a command and data acquisition station (CDAS) at Wallops Island, Virginia. The measurements are made by the Visible infrared spin scan radiometer Atmospheric Sounder (VAS). The VAS operates at multiple wavelengths; its best resolution is 0.9 km in visible

light and 6.9 km in infrared. The second function of the satellites is to relay processed VAS data and other weather data from the CDAS to receivers at various user locations. The third function is to provide two-way communications between the CDAS and many unattended data collection platforms. The Japanese Geostationary Meteorological Satellites have the same function and design [4]. The ESA Meteosats [5,6] are similar.

Two Synchronous Meteorological Satellites were predecessors to the GOES. They and GOES 1 to 3 were of the same design. Beginning with GOES 4, the radiometer was improved to become the VAS, and the satellite design changed. The GOES 4 version of the satellite is shown. The cylindrical body, VAS, and VAS sunshade are joined and spin to provide stabilization. The spinning also provides the east-west scanning motion for the VAS; north-south scanning is accomplished by tilting an internal mirror. The antenna assembly is despun and continuously points toward the earth. All communications and support equipment is mounted inside the body. A rotary joint connects the antennas to the communications electronics. The satellite also has a magnetometer, x-ray sensor, and other sensors for monitoring the space environment.

In the GOES communication subsystem, the 28 Mbps VAS data are brought into the S-band receivers, and QPSK modulate an 84-MHz carrier. This carrier is upconverted, then amplified in the S-band driver and transmitter stages for transmission to the ground. The VAS views the earth, and outputs data, for only 37.5 msec of every 600-msec spin period. During the remaining time, the modulator is disconnected, and signals received through the S-band antenna are retransmitted at S-band. These signals include processed VAS data at 1.7 Mbps and weather facsimile data at lower rates. Every 30 min, enough processed data are transmitted to produce a global picture of cloud patterns and temperature profiles. This S-band channel also is used for low duty cycle transmissions of ranging signals between three widely separated stations.

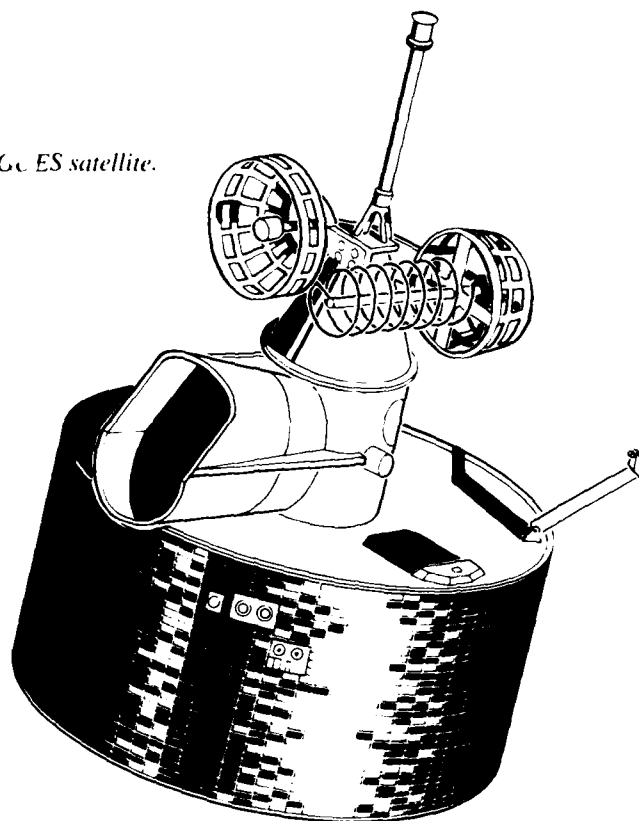
The CDAS may interrogate data collection platforms (DCP) via a link transmitted to GOES at S-band. An intermediate frequency signal from the S-band receivers is routed to the UHF receivers and retransmitted to the platforms at UHF. Return UHF signals from the platforms are received and routed to the DCP transmitter which operates at S-band. The DCPs monitor such parameters as pressure, temperature, rain, snow, river levels, and ocean currents. Their transmissions, at 100 bps, are initiated by interrogation from the CDAS, an internal timer, or occurrence of a specific phenomenon. The GOES return channel can accommodate up to 188 simultaneous transmissions on separate frequencies.

The GOES system normally uses two operating satellites, located at 75°W and 135°W longitude, which together provide good coverage of the United States and offshore areas. At the beginning of 1986, only GOES 6 was fully active, and it was placed at a location near 100°W longitude. Some of the earlier satellites provided support using subsystems that had not failed, e.g., GOES 5, which cannot produce images but still has communications capability. In 1987, GOES 7 was launched and two-satellite imaging was restored. The VAS on GOES 6 failed in 1989, and GOES 7 was moved to 107°W longitude. GOES 6 continued to provide communications. The satellite details are as follows:

Satellite

Cylinder, 85-in. dia. (GOES 4 and subsequent), approximately 40-in. height (GOES 4 and subsequent), height including antennas, 143 in.

GOES satellite.



975 lb (GOES 4 and subsequent) in orbit

Solar cells and NiCd batteries, 320 W (GOES 4 and subsequent) after seven years

Spin-stabilized, 100 rpm, ± 0.1 -deg pointing accuracy

Configuration

A: transmission of 28 Mbps data generated onboard, time-shared with retransmission of received data (all S-band)

B: one transponder for transmissions from a central station to remote platforms (S-band to UHF)

C: one 200-kHz bandwidth transponder for up to 188 FDMA, 100 bps transmissions from remote platforms to a central station (UHF to S-band)

Transmitter

A: 1681.6 MHz for internal data, 1687.1 and 1691 MHz for retransmitted data

20-W output, approximately 26-dBW ERP at edge of earth

B: 468.825 MHz, 4-W output, approximately 16-dBW ERP at edge of earth

C: 1694.5 MHz, 0.5-W output, 6.5-dBW ERP at edge of earth

Receiver

A: 2029.1 and 2033 MHz, -17.6 dB/K G/T at edge of earth

B: 2034.9 MHz, -17.6 dB/K G/T at edge of earth

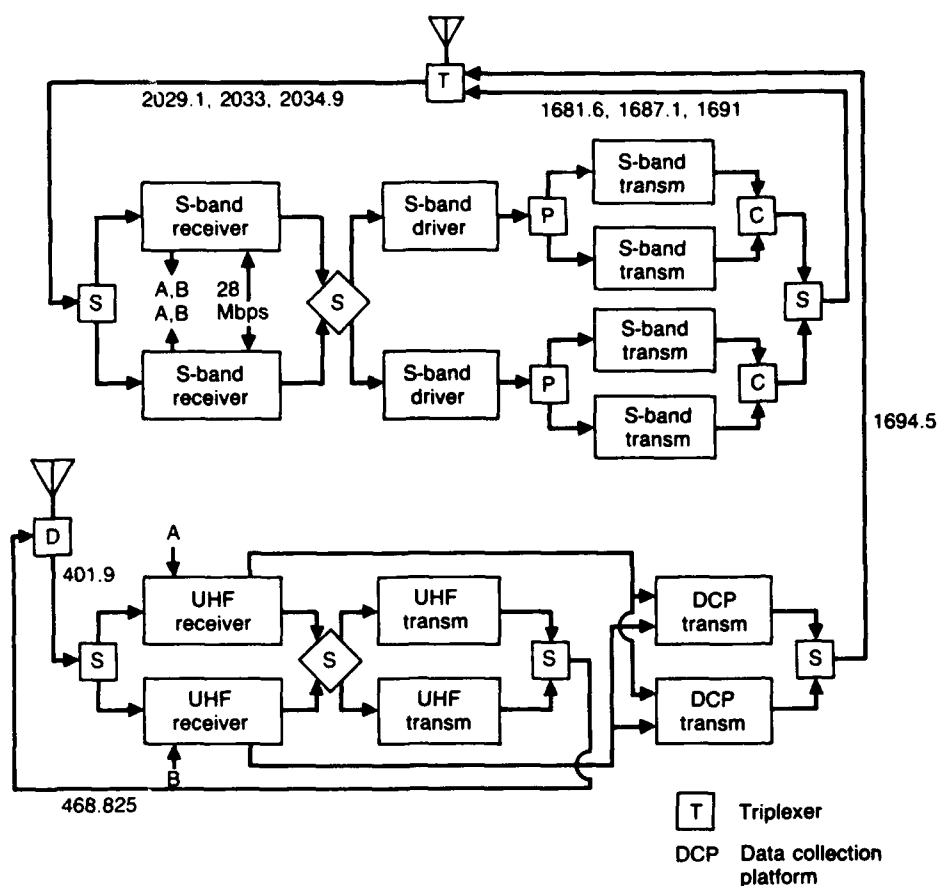
C: 401.9 MHz, -18.5 dB/K G/T at edge of earth

Antenna

One vertically polarized S-band parabolic antenna and one RHCP UHF helix, each has an earth coverage beamwidth

Design life

Seven years (GOES 4 and subsequent)



GOES communication subsystem.

Orbit

Synchronous equatorial, normally 75°W and 135°W longitude

Orbital history

SMS 1: launched 17 May 1974, moved to higher altitude after useful life

SMS 2: launched 6 February 1975, moved to higher altitude after useful life

GOES 1: launched 16 October 1975, moved to higher altitude after useful life

GOES 2: Launched 16 June 1977, moved to higher altitude

GOES 3: Launched 16 June 1978, failed

GOES 4: launched 9 September 1980, moved to higher altitude

GOES 5: launched 22 May 1981, failed

GOES 6: launched 28 April 1983, VAS failed January 1989, communications still active, 135°W longitude

GOES G: launch vehicle failure May 1986

GOES 7: launched 26 February 1987, active, 107°W longitude

GOES I (8 after launch): probable launch late 1992 or 1993

GOES J (9 after launch): probable launch 1993

Delta 2914 launch vehicle (through GOES 3)

Delta 3914 launch vehicle (GOES 4 to 6)

Delta 3920 launch vehicle (GOES 7)

Atlas Centaur launch vehicle (GOES I, J)

Management

Developed by Ford Aerospace (through GOES 3 and 8 to 12), Hughes Aircraft Company (GOES 4 to 7), for NASA, acting for National Oceanic and Atmospheric Administration (NOAA)

Operated by NOAA

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1. A. M. Nakamura and L. A. Mallette, "Geostationary Operational Environmental Satellite (GOES) Telemetry and Communications," *International Telemetry Conference Proceedings* (November 1981).
2. L. R. Fermelia, "GOES Communication Subsystem," *International Telemetry Conference Proceedings* (November 1981).
3. L. A. Mallette, "Geostationary Operational Environmental Satellite (GOES): A Multifunctional Satellite," Paper 82-0536, *AIAA 9th Communications Satellite Systems Conference* (March 1982).
4. Y. Horikawa and M. Saito, "In-Orbit Operations of Japanese Geostationary Meteorological Satellite, GMS-2 'Himawari 2'," *Earth-Oriented Applications of Space Technology*, Vol. 4, No. 1 (1984).
5. D. Leverington, "The Meteosat Space Segment," *ESA Bulletin*, No. 11 (December 1977).
6. A. Robson and H. Hovet, "The Meteosat Data-Collection System and Its Applications," *ESA Bulletin*, No. 21 (February 1980).

SATELLITES P76-5, P83-1, AND P87-1

Satellite P76-5 was one of many scientific satellites launched by the Air Force Space Test Program. Its payload was a multifrequency radio beacon called the DNA (Defense Nuclear Agency) Wideband experiment [1]. The experimental program using this beacon was designed to characterize the perturbations imposed on radio waves as they propagate through structured plasmas in the ionosphere. The program included measurements of amplitude fading and phase scintillations as functions of time, frequency, and location.

The Wideband experiment transmitted ten phase-coherent signals, all derived from a single crystal oscillator. The ten frequencies included one VHF, seven UHF, one L-band, and one S-band. Specific frequencies are delineated below. The S-band signal served as an undisturbed (at most times) phase reference for the lower frequencies. All were transmitted with circular polarization.

The P76-5 satellite was a modified Transit satellite from the Navy navigation satellite program. The modification was primarily substituting the Wideband experiment for the navigation payload. The satellite body was an octagonal cylinder. A gravity-gradient boom was deployed from the satellite in the antiearth direction, and four solar panels unfolded into the plane normal to the boom, spaced 90 deg apart. The experiment's antenna was on the earth-facing side of the satellite. The satellite details are as follows:

Satellite

Octagonal cylinder 12-in. height, 18-in. dia.; height with gravity-gradient boom approximately 100 ft; span across opposite solar panels approximately 40 ft

Approximately 110 lb in orbit

Solar array and NiCd batteries, 45 W beginning of life

Gravity-gradient stabilization

Transmitter

137.675 MHz	12th Harmonic	26-dBW ERP
378.606	33rd	27
390.079	34th	26
401.552	35th	30
413.024	36th	27
424.497	37th	27
435.970	38th	25
447.443	39th	28
1239.073	108th	25
2891.171	252nd	27

Antenna

Several radiators with a 60-in. ground plane, approximately earth

coverage beams with lower gain at beam center to approximate uniform coverage, RHCP

Orbit

532 × 567 nmi, 99.6-deg inclination, sun synchronous

Orbital history

Launched 22 May 1976

Scout launch vehicle

Management

Developed by RCA (satellite) and Stanford Research Institute (experiment) for Defense Nuclear Agency

Satellite P83-1, also called the HiLat satellite [2, 3], was another Air Force Space Test Program launch. It had five experiments to study and characterize behavior of the ionosphere at high latitudes. One experiment was a multifrequency beacon, for amplitude and phase scintillation measurement, which was a successor to the Wideband experiment on P76-5. The beacon frequencies were the 138-, 390-, 413-, 436-, and 1239-MHz lines of the Wideband spectrum. They were transmitted circularly polarized. The 250-lb P83-1 was launched on 27 June 1983 by a Scout launch vehicle into a 430-nmi circular orbit at 82-deg inclination.

HiLat was followed by P87-1, the Polar BEAR (Beacon Experiment and Auroral Research) satellite [3, 4]. Its purpose was to help characterize the ionosphere near the north pole, with a view to improving communications. The Polar BEAR had three experiments; one was an improved version of the HiLat beacon. The spacecraft supporting these experiments was a former Navy Transit navigation satellite. This spacecraft had been on display for eight years in the Smithsonian Air and Space Museum. It was requisitioned and refurbished for Polar BEAR, because no other spare Transits existed; a test model of Transit took its place in the museum. The 275-lb Polar BEAR was launched on 13 November 1986 by a Scout into a 625-nmi orbit.

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1. E. J. Fremouw, et al., "Early Results from the DNA Wideband Satellite Experiment," *Radio Science*, Vol. 13, No. 1 (January-February 1978).
2. E. J. Fremouw, et al., "The HiLat Satellite Mission," *Radio Science*, Vol. 20, No. 3 (May-June 1985).
3. J. W. Powell, "The Space Test Programme—An Update," *Journal of the British Interplanetary Society*, Vol. 40, No. 11 (November 1987).
4. *Aviation Week & Space Technology* (10 November 1986), p. 27; (1 December 1986), p. 41.

ENGINEERING TEST SATELLITE-II

The Japanese Engineering Test Satellite-II (ETS-II or Kiku II) was a beacon satellite whose objectives were to develop and test Japan's ability to launch and control a synchronous orbit satellite and to make propagation measurements [1-3]. The ETS-II was a United States-built satellite with a design that was basically the same as Skynet I. It was a spin-stabilized satellite with a set of three antennas that were despun. Each antenna was used for one of the beacon transmissions, which were at 1.7, 11.5, and 34.5 GHz. All three frequencies were derived by multiplication from a

common oscillator at about 213 MHz. The propagation measurements in the ETS-II program were signal level and cross-polarized level at each frequency and phase differences between several pairs of signals and cross-polarized components. The satellite design details are as follows:

Satellite

Cylindrical body, 55-in. dia., overall height, 71.5 in.
286 lb in orbit

solar cells and NiCd batteries, 92 W minimum after one year pin-stabilized, approximately 100 rpm, ± 0.5 -deg antenna pointing accuracy

Configuration

Three beacon transmitters

Transmitter

1.705 GHz: CW or 100% amplitude modulation by 300-Hz square wave, 6-dBW measured ERP

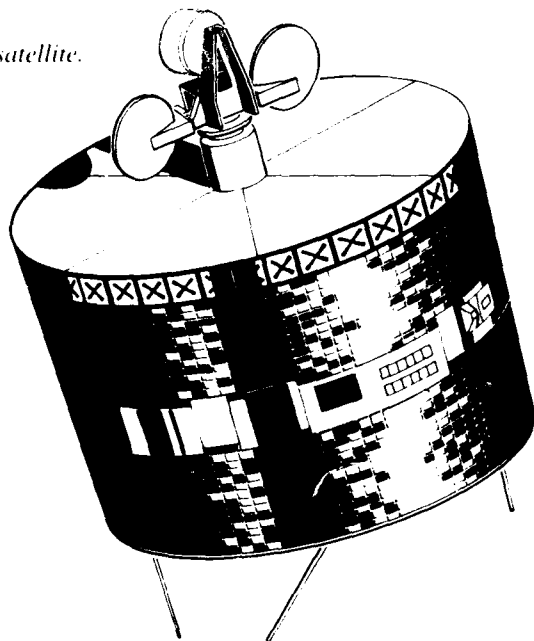
1.50875 GHz: CW, 20-dBW measured ERP

4.52625 GHz: CW or 100% amplitude modulation by 300-Hz square wave, 24-dBW measured ERP

Antenna

Two parabolic reflectors, one each for 11.5 and 34.5 GHz, 2.2-deg beamwidth at 34.5 GHz

ETS-II satellite.



One end-fire antenna in a cavity for 1.7 GHz

Design life

One year

Orbit

Synchronous equatorial, 130°E longitude, E-W stationkeeping to ± 0.5 deg

Orbital history

Launched 23 February 1977

Operations ended May 1978

Japanese N launch vehicle

Management

Developed by Ford Aerospace and Communications Corporation under contract to Mitsubishi for National Space Development Agency of Japan

Operated by NASDA

ETS-II was launched from Tanegashima, Japan, in February 1977. The launch vehicle was a Japanese N rocket, built under license and based on the 1970-style Delta launch vehicle. This launch served as a test of the N rocket and control network for the J ECS launch in 1979. Initial tests were conducted in March 1977, and the propagation experiment was operated from April 1977 to May 1978.

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1. M. Hirai, et al., "Development of Experimental and Applications Satellites," *Acta Astronautica*, Vol. 7, No. 8-9 (August-September 1980).
2. R. Hayashi, Y. Furuhashi, and N. Fugono, "Propagation Characteristics for Millimeter and Quasi-Millimeter Waves by Using Three Japanese Geostationary Satellites," *Acta Astronautica*, Vol. 7, No. 11 (November 1980).
3. N. Fugono and R. Hayashi, "Propagation Experiment in 1.7, 11.5, and 34.5 GHz with Engineering Test Satellite Type II," Paper 78-623, *AIAA 7th Communications Satellite Systems Conference* (April 1978).

SARSAT-COSPAS

Many aircraft and ships carry small transmitters that may be used to broadcast emergency signals. However, because of their limited power, they have a short range. Thus, in most cases, rescue organizations must be alerted to the emergency by other means and home on the transmitted signal only after they reach the vicinity of the emergency. Since satellites can see a large portion of the earth, they have a much better chance of receiving these emergency signals. Canada tested this concept in 1975 using an Oscar satellite. Satellite reception is now being used in a program called Sarsat (search and rescue satellite-aided tracking) [1-16]. In the Soviet Union, it is called Cospas, from the Russian words for Space System for the Search of Distressed Vessels. This program, a cooperative effort of the United States, Canada, France, and the Soviet Union, formally started in 1980. Since it started, five other nations have become associated with it.

The emergency transmitters, which were developed in the 1970s, transmit a distinctively modulated signal. The transmis-

sion is continuous from activation as long as power is available. Civilian transmitters use 121.5 MHz and military transmitters use 243 MHz. Improved transmitters were made available beginning in 1985; they transmit in the 406- to 406.1-MHz band. They have improved frequency stability, which simplifies the processing required to extract position information from the received, Doppler-shifted frequency. In addition, they transmit only a 440- or 520-msec burst approximately every 50 sec. Thus, multiple transmitters within view of one satellite will have a small probability of interfering with each other. Finally, their burst transmissions may contain data that will include the identity of the vessel in trouble and perhaps also its estimated location.

The first Sarsat-equipped satellite was Cosmos 1383, launched in June 1982. The second was the United States NOAA 8 weather satellite launched in March 1983. The third was Cosmos 1447, launched in the same month. Another Cosmos and NOAA 9 were launched in 1984. Cosmos 1383 was operating only intermittently

by 1985, but the other four satellites comprised the agreed-on operational constellation of two satellites each from the United States and the Soviet Union. NOAA 8 failed at the end of 1985 and was not replaced until NOAA 10 was launched in September 1986. NOAA 11, launched in September 1988, replaced NOAA 9, and the fourth and fifth Cospas-equipped Cosmas satellites were launched in August 1989 and March 1991. All of these satellites are in polar orbits at altitudes between about 400 and 550 nmi. The polar orbit provides coverage of northern latitudes not visible to synchronous orbit, and the motion of the satellite over the beacon generates the Doppler shift used for position estimation. The Cosmos satellites have 121- and 406-MHz receivers. The NOAA satellites have Canadian-built 121- and 243-MHz receivers and a French-built 406-MHz receiver and processor. All the satellites retransmit received signals at 1544.5 MHz. Signals received at 121 and 243 MHz are retransmitted in real time only; if no ground station is in view, the signal is lost. In contrast, the 406-MHz signals are processed on the satellites; the resultant data are retransmitted immediately and stored for later transmission to other ground locations.

By 1986, there were three Sarsat ground stations (called Local User Terminals, LUTs) each in the United States and the Soviet Union and one each in France and Canada. Ten have been built in other countries since then. Each station can receive signals from any satellite whenever it is in view. The stations process the signal to determine the location of the transmission. Location accuracy is about 12 nmi with the older transmitters, and better than 2 nmi with the new 406-MHz transmitters.

Information received at a LUT is sent to a national mission control center. These exist in the United States, Soviet Union, France, Canada, United Kingdom, Norway, and Brazil. These centers communicate with each other and with rescue coordination centers belonging to the agencies that conduct rescues. As many as six more nations are expected to build mission control centers by 1992.

The Sarsat demonstration began with the Cosmos 1383 launch. The first rescue supported by the satellite occurred in Canada in September 1982. Since then, the system has aided various rescue attempts. The speed of the Sarsat-aided rescues is credited with saving over 100 lives by the end of 1983, over 500 by mid-1986, and over 1200 by early 1989, as well as reducing risk to searchers.

Expansions of the system are being investigated. Although the current set of eighteen LUTs can see a Sarsat or Cospas satellite almost anywhere north of the equator, there are coverage gaps south of the equator. Even with the 406-MHz capability, these gaps become time delays in the rescue process. With the older beacons, no capability is available in the gaps. Even if the gaps were filled, several hours could elapse before one of the satellites passed in view of a beacon. Therefore, synchronous altitude satellites are a supplementary resource. They have constant visibility to about one-third of the earth but, being farther away, they require more beacon power. Tests began with GOES 7 in 1987-1988. Additional tests were conducted with Inmarsat satellites and 1.6-GHz beacons.

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DOD LIGHTSATS

For about a decade, DARPA has been investigating small, low-cost satellites as a supplement to the large satellites currently used by DoD. The emphasis for these small satellites, called Lightsats, is survivable, quick-reaction launches and direct support to military forces in the field. Many missions have been proposed for Lightsats.

Four projects have produced Lightsats for communications [1-4]. The satellite designs are summarized in Table 1. The Global

ejection mechanism failed during an April 1985 Shuttle mission, but the satellite was successfully ejected during an October 1985 mission. The initial orbit altitude was 176 nmi. GLOMR operated successfully and accomplished its mission objectives. Due to atmospheric drag, its altitude decreased and its orbit decayed in December 1986, at which time it was still working.

The Multiple Access Communications Satellites (Macstats) are two identical Lightsats launched on a Scout in May 1990. They each have a digital store-and-forward capability similar to that of GLOMR. Like GLOMR, satellite operations and communications control is provided by an 80C86 microprocessor in the satellite.

The Microstats are smaller: seven were attached to one dispenser for a Pegasus launch in July 1991. They achieved a lower altitude than planned, reducing their life to one year. Each satellite has a microprocessor-controlled digital communications payload. The payload is similar to that on the Macstats but without the same redundancy and with less memory. Microstats can be used for bent-pipe or store-and-forward communications.

The Small Experimental Communications Satellite (SECS) is a Navy satellite based on the GLOMR design. It was launched as a secondary satellite on the first Pegasus launch, attached to Pegsat, the primary satellite, and separated in orbit.

* * * * *

PROJECT	GLOMR	MACSAT	MICROSAT	SECS
Shape	many sided, approximately spherical	cylinder	12-sided cylinder	many sided, approximately spherical
Size	16-in. dia.	24-in. dia., 14-in. dia.	19-in. dia., 14-in. tall	16-in. dia.
Weight	150 lb	150 lb	50 lb	150 lb
Solar array output	8-W peak, 4-W average	9-W average	23-W peak, 3- to 8-W average	8-W peak, 4-W average
Battery type	lead acid	NiCd	NiCd	
Stabilization	spin	gravity gradient	spin	spin
Frequency band	UHF	UHF	UHF	UHF
Transmitters	2 (1 spare) 10-W output	2 (1 spare) 10-W output	1, 10-W output	2 (1 spare) 10-W output
Receivers	2 (1 spare)	2 (1 spare)	1	2 (1 spare)
Modulation	BPSK, FSK	BPSK, FSK	FSK	
Rates	1.2 kbps	1.2 or 2.4 kbps	up to 9.6 kbps	
Design life		1 yr required 3-yr goal	1 yr required, 3-yr goal	
Initial orbit	176 nmi, 57-deg incl.	490 nmi, polar	190 x 245 nmi, 82-deg incl.	315 nmi, polar
Launch date	October 1985	May 1990	July 1991	April 1990
Launch vehicle	Shuttle	Scout	Pegasus	Pegasus
Sponsor	DARPA	DARPA	DARPA	Navy
Contractor	Defense Systems, Inc.	Defense Systems, Inc.	Defense Systems, Inc.	Defense Systems, Inc.

Low Orbiting Message Relay (GLOMR) was the first of them, and the first of any type of DoD Lightsat. The goal of the project was to show the feasibility of building a satellite in less than one year and to demonstrate a digital communications capability in orbit. The communications payload capabilities included command and readout of unattended ground sensors, store and forward messaging for military users, and location of transmitters by the doppler shift of the received signal.

The GLOMR satellite fits in a Shuttle Getaway Special canister. In orbit, the canister lid opens and the satellite is ejected. The

1. *Aviation Week & Space Technology* (15 April 1985), p. 14; (6 May 1985), p. 20; (28 October 1985), p. 20; (4 November 1985), p. 20; (18 September 1989), p. 34; (13 November 1989), p. 29; (27 November 1989), p. 96; (16 April 1990), p. 24; (30 July 1990), p. 78; (22 July 1991), pp. 24, 25.
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OTHER SMALL SATELLITES

Small satellites with digital store-and-forward message payloads have become popular since the late 1980s [1]. The major groups are the amateur radio operators' Oscar satellites and the DoD Lightsats. Other organizations are building similar satel-

lites, using microelectronics to obtain a useful capability in a small satellite.

Four satellites, UoSAT 5 (described earlier), Tubsat, SARA, and Orbcomm X, were launched in July 1991 as secondary

payloads on an Ariane rocket. The Technical University of Berlin built Tubsat, a 66-lb satellite with a store-and-forward payload. One use of the payload will be to relay data from transmitters on animals, and to locate the transmitters using doppler measurements.

SARA is a 40-lb satellite built in France. Its purpose is to receive radio emissions from space and retransmit them to earth.

Orbcomm X [2] is a 26-lb satellite built by Orbital Sciences Corporation. It is a prototype for a low orbit system for mobile communications, for which Orbital Sciences has submitted an application to the United States Government. The purposes of Orbcomm X were to do a spectrum survey in the bands for the proposed system and to demonstrate packet radio communications. Both purposes would have contributed to reduced uncer-

tainties in the system design. However, Orbcomm X ceased operating less than one day after launch.

Sweden had announced plans for a store-and-forward mail satellite named Mailstar. The payload for this satellite was later combined with a technology payload onto a new satellite called Freja. The planned launch is at the end of 1992 on a Pegasus launch vehicle.

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1. *Aviation Week & Space Technology* (1 January 1990), p. 38; (5 February 1990), p. 77; (2 April 1990), p. 26.
2. G. E. Hardman, "Engineering Orbcomm: A Digital Satellite Communications System Exploiting a Range of Modern Technologies," *Third IEE Conference on Telecommunications*, IEE Conference Publication No. 331 (1991).

SATELLITE COMMUNICATIONS TO THE YEAR 2000

Without a doubt, the field of communication satellites will continue to grow. Present domestic, regional, international, and military systems will introduce new generations of satellites. The slowest growth will be in the military systems. As a whole, domestic and regional systems will grow, but growth will vary considerably in different parts of the world. The United States and Canadian domestic systems, being the most mature, will have the slowest growth. The rapid growth will still be in the new domestic systems of both industrialized and developing countries. Domestic systems' growth will continue to include both dedicated satellites and purchases and leases from Intelsat. Both the Intelsat and Inmarsat international systems also will grow. Fiber optic transmission systems are coming into use and have been discussed as a competitor that will slow satellite growth. This assertion is based on their tremendous capacity—about 500 Mbps per fiber and about two dozen fibers per cable at the present time. Obviously, the capacity is many times that of, for example, a 24-transponder satellite at 60 Mbps per transponder. However, fiber optics are limited by their point-to-point routing and distance-sensitive costing. Communications satellites are not subject to either restriction; thus, both media should find many opportunities for expansion.

The largest new application of satellites will be in mobile communications. Marisat and Inmarsat pioneered service to ships. In the late 1980s, Inmarsat tested communications to airplanes, and operational service has begun. Inmarsat also is providing service to land mobile users. New systems for mobile users are part of Aussat B and, by 1994, the MSat system in North America. Coverage should expand to other parts of the earth in the second half of this decade. The systems in development all use synchronous orbit satellites, but several low-orbit multisatellite systems have been proposed also. Perhaps one or more will be operating by 1996. The primary engineering change for the synchronous satellites will be increased antenna diameters, to about 18 to 25 ft. Follow-on satellites, launched near the end of the decade, will use much larger antennas (at least 50 ft) to multiply capacity by frequency reuse in multiple beams.

Satellite broadcasting will grow, but at a pace slower than has been predicted. The emphasis of the broadcasting is television, but high-quality sound broadcasting also is being done. Although a few high-power broadcasting satellites are being used in Europe and Japan, the growth in this application will be primarily, perhaps solely, from ever higher-powered communication satellites. Low-power broadcasting is well established in the United States as a by-product of television distribution for network and cable use. Medium-power broadcasting has followed the same path, but with increasing recognition that home receivers are no longer a secondary market, but a primary one. Both Eutelsat and Astra have considerable business in 12-GHz, medium-power broadcasting in Europe. These, and national systems, will continue to grow. By the turn of the century, it is probable that the high-power broadcast satellite will no longer exist as a distinct type of communications satellite. Rather, general communications satellites will provide both television broadcasting and voice/data services to ever larger numbers of ground terminals with small antennas.

The demand for business communications is obvious in the developed countries and is expected to increase substantially. Satellite capacity was adequate in the United States and Europe but was nonexistent in Japan until 1988. Business communica-

tions are centered on the 12/14-GHz band, where exclusive satellite allocations in some countries eliminate interference problems and permit siting of relatively small terminals at customer locations. The increasing demand within countries and internationally is being met by satellite designs with more channels, more routing flexibility, and higher transmitter powers. For many business communications needs, low to moderate data rates are sufficient, and very small aperture terminals (VSATs) may be used. VSATs typically have antenna diameters of 3 to 6 ft and are common in the United States. Substantial numbers of VSATs are coming in Europe, and they also are spreading to other countries, including less developed countries.

To keep pace with increasing capacity demands for all types of satellite communications, new features will be incorporated into satellite and system designs. The 1970s saw a relatively full exploitation of the 4/6-GHz band, and the 1980s produced the same for the 10- to 14-GHz bands in the developed countries. Although use of the 20/30-GHz band has begun with the Japanese CS, large-scale use of these bands will occur in the late 1990s to early 2000s after the preliminary investigations with Olympus, Italsat, and ACTS. In addition, experiments in the 40- and 50-GHz bands will be conducted in the 1990s. At the same time, less-developed countries will seek greater use of the 4/6-GHz band for communications and education for national development, with an emphasis on low cost and simple ground hardware.

Antenna evolution also will contribute to increased capacity. Shaped beams, using multiple feed horns, have been used for several years, with Intelsat having the most advanced designs. These antennas will continue to increase in sophistication. The use of spot beams will grow and their beamwidth will decrease, leading to greater frequency reuse. Italsat is the first to use many spot beams in one country. Satellites that cover the United States or Europe with dozens of independent spot beams have been discussed but are unlikely to be launched this decade. Another concept that has been studied is a scanning spot beam. This will be tested on ACTS and may be in use by the mid-1990s. Although this technology can be applied to any frequency, the biggest use will be above 10 GHz, where reasonably sized reflectors (e.g., up to 10- to 12-ft diameter) can be used to produce narrow beams.

The use of signal processors in satellites is another design step that will provide capacity growth. The processing can include switch matrices, either IF or baseband, which operate at a TDMA burst rate; demodulation and remodulation; demultiplexing and multiplexing of bit streams; coding and decoding; and routing of messages by reading headers. Early applications of these techniques are on Intelsat VI, Olympus, Italsat, and ACTS. Some of these techniques will, of necessity, come into use on multibeam satellites to efficiently interconnect a ground terminal population divided among many beams.

Less complex, but also significant, contributors to system capacity are receiver noise reductions and power amplifier improvements. The noise reductions are due to the development of GaAs field effect and high electron mobility transistors, which are in use now in ground and space receivers. Improvements from 1984 to 1990 yielded up to four times the capacity if other parameters remain constant, or reduced requirements on other equipment. The improvements are continuing but may reach practical lower limits by mid-decade. Transmitter power amplifiers are either TWTAs or solid state. The practical power levels for satellite

TWTAs have doubled approximately every decade. The efficiencies also have improved, although at a slower rate. Solid-state amplifiers have become the most common satellite power amplifier at 4 GHz. Typical power levels are about 10 W, although 20-W amplifiers also exist. Downlink power density regulations will cause these power levels to remain about the same in the future. Although they have lower power conversion efficiency, they contribute significantly to greater capacity, because their distortions are lower than those of TWTAs. At 12 GHz, solid-state amplifier capabilities are less than at 4 GHz, but typical satellite transmitter powers (with TWTAs) are much higher due to bands without power density regulations. Therefore, there will be little use of 12-GHz solid-state amplifiers throughout the decade.

Operational use of intersatellite links started in 1983 with TDRS. The use of these links between synchronous altitude satellites has been studied for several years. However, their use will probably not occur until after the mid-1990s. Potential benefits include positioning of satellites to improve ground elevation angles or to avoid crowded sections of the orbit, interconnecting widely spaced satellites to avoid double hop links, and interconnecting various types of satellites (e.g., mobile satellite to Intelsat) to provide more direct or flexible routing of links.

Enhancements of transmission techniques also will contribute to improved capacity. This covers modulation, coding, bandwidth compression, and multiple access methods. Ground hardware plays the predominant role here, and application of available technology will be more significant than development of new technology. Nevertheless, developments will continue and will eventually be brought into use. The most activity is in the area of voice processing to increase the number of voice circuits per unit bandwidth. Specific techniques that are already used occasionally, but should see significant use in the 1990s, include digital speech interpolation, companding, delta modulation, and voice encoding. In addition, video bandwidth compression techniques will be important, both for full rate and slow scan transmissions. Also, the use of TDMA will increase, and modulation formats with improved spectral efficiency may be applied to operational systems.

Spacecraft technology will progress to support larger or more complex communication subsystems. A major effort at present is in large lightweight solar arrays that can provide 3 to 6 kW of power. These are most necessary for broadcast satellites or communication satellites with many high-power transponders. Nickel hydrogen batteries have been flown on several satellites and, by the start of the 1990s, will displace nickel cadmium batteries in high-power satellites. In propulsion subsystems, several satellite designs are incorporating unified bipropellant systems and/or electrothermal thrusters. Both provide improved performance-to-weight ratios. The next step will be electric propulsion for stationkeeping, which will be used first in 1993. Attitude control accuracies have been improved to satisfy requirements for more accurate antenna pointing, while at the same time coping with the motions of large flexible appendages. Whereas ± 0.1 -deg pointing characterized the 1970s, ± 0.05 deg is not unusual now. The major contributor to the improvement is the use of satellite receivers that track ground-based beacons. Except for unusual applications, beamwidths will not decrease much more this decade, so attitude control accuracies of ± 0.05 to ± 0.1 deg will continue. Structurally, graphite composites and beryllium are already in common use where low weight and stiffness are important. The composites also have very low thermal expansion coefficients. The mechanical challenge of future communication satellites will probably be in ever larger antennas and their deployment and steering mechanisms. Large deployed antennas and solar arrays will require more sophisticated controls to counter the motions of these assemblies and maintain accurate antenna pointing.

Large space platforms have been discussed since about 1980. Sizes as large as 200 ft have been considered, with each platform accommodating many communication subsystems. As an alternative, clusters of conventional satellites, joined by intersatellite links, have been proposed. While both concepts have their merits, they face institutional problems as well as technical problems. These platforms or clusters are unlikely to be launched until after the turn of the century.

APPENDIX A

THE ITU AND INTERNATIONAL FREQUENCY ALLOCATIONS

The International Telecommunication Union (ITU) is a specialized agency of the United Nations [1-15]. At present, about 166 nations are ITU members, including all the major world powers and all countries which use satellite communications. The objective of the ITU is to promote international cooperation in the efficient use of telecommunications. Activities toward this end, related to frequency allocations and their use, are the following:

- Prepare regulations.
- Allocate the radio frequency spectrum.
- Register radio frequency assignments and geostationary satellite longitudes.
- Coordinate efforts to eliminate harmful interference.
- Adopt resolutions and formulate recommendations concerning telecommunications matters.

The governing document of the ITU is the International Telecommunication Convention. The highest decision-making body is the Plenipotentiary Conferences. The work of the ITU is done in both periodic international conferences and by permanent agencies with staffs at Geneva.

The ITU Radio Regulations include, among other things, the Table of Frequency Allocations, procedures for notification, registration, and coordination of new or modified uses of the frequency spectrum, and provisions to limit interference between users of the frequency allocations. The Regulations, when ratified by the member nations, have the legal force of a treaty.

Revision of the Radio Regulations is carried out in general and special World Administrative Radio Conferences (WARCs) and in Regional Administrative Radio Conferences (RARCs). A general WARC was held in 1979 and was authorized to consider a complete revision of the Radio Regulations. The previous general WARC was in 1959, and the next is expected about 1999. Specialized WARCs and RARCs occur more often. Each is chartered to address revisions of the Radio Regulations concerning a specific topic. Conferences that considered satellite matters have included the WARC for Space Telecommunications (1971), the WARC for Satellite Broadcasting (1977), the RARC for Satellite Broadcasting in Region 2 (1983), and the WARC for Mobile Services (1987). The most important satellite conference since 1979 was the two-part WARC on the Geostationary Orbit (WARC-ORB-85, 88). WARC-92 will cover a variety of frequency allocation issues, some of which are for space.

The International Frequency Registration Board (IFRB) is one of the permanent ITU agencies. It is responsible for maintaining the international list of frequency assignments for both earth and space stations. This responsibility includes the process of notification, coordination, and registration of new and modified frequency assignments, including those for space systems. The process is basically as follows:

- Several years before a new system comes into use, the national administration notifies the IFRB of its technical characteristics.
- These characteristics are published in the weekly IFRB circular.
- Any administration concerned about potential harmful interference from the proposed system may make comments to, and request coordination with, the notifying administration.

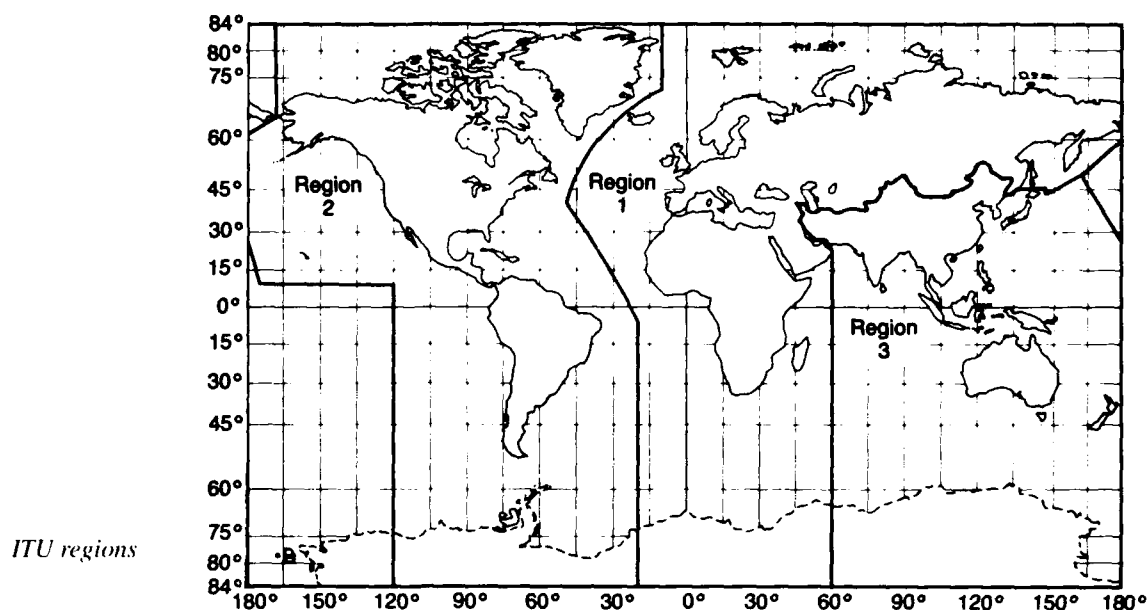
- The coordination may result in modifications to the proposed system, and if necessary thereafter, modifications to existing systems.
- The IFRB reviews the proposed system in light of the Radio Regulations, current spectrum usage, and the results of Steps 3 and 4.
- If all of the preceding are satisfactory, the IFRB registers the system by publication in the Master International Frequency Register, which is intended to guarantee that it will not be subject to harmful interference from systems which have yet to be registered.

The foregoing process is characterized by first come, first served. Since the late 1970s, the developing countries have expressed a strong concern that the industrialized countries' satellites will use up the desirable synchronous orbital locations and frequencies. This would force the developing countries, whose use of the orbit and spectrum lags that of the industrialized countries, to use less desirable locations and/or frequencies, and at greater cost. Therefore, they advocate a guaranteed access process to replace the current process. The developing countries prefer an explicit allocation of orbit locations and frequencies to each country, whereas the industrialized countries prefer a more flexible approach. Equitable and guaranteed access to the synchronous orbit, and the method to achieve it, was the subject of WARC-ORB-85, 88. The first session worked out principles and methods of planning and narrowed the choices of services and frequency bands to which they would apply. The second session developed a global allotment plan for the fixed-satellite service in frequency bands little used yet and improved the coordination procedures for the bands in common use. The plan guarantees each nation at least one orbit slot within a predefined arc, and 800 MHz of bandwidth.

The CCIR (from the French for International Radio Consultative Committee) is another permanent ITU agency. It studies technical and operational questions in the field of radio communications. The CCIR is organized into more than a dozen specialized study groups. Those most relevant to the satellite communications are

- Group 1—Spectrum Utilization and Monitoring.
- Group 4—Fixed Service Using Communication Satellites.
- Group 9—Coordination and Frequency Sharing Between Systems in the Fixed-Satellite Service and Terrestrial Radio-Relay Systems.

In addition, the Mobile and Broadcasting Services groups study matters related to satellites. Each study group or working parties and task groups, which have representatives from any nation interested in its work, meet once or more a year. Much of the group's work depends on inputs from national study groups. The United States has active national study groups corresponding to each of the CCIR groups. Every four years, the entire CCIR has a Plenary Assembly. The assembly considers new recommendations, modifies existing recommendations, prepares resolutions, and considers the study program for each group for the next four years. Recommendations, reports, and resolutions are published after every Plenary Assembly. Although the CCIR outputs are not binding, they are often adopted by international or national



agencies as technical standards. In addition, the CCIR has preparatory meetings six months to one year before WARCs.

The Radio Regulations define thirty-eight radio services and specify which services are allowed to use each portion of the spectrum between 9 kHz and 275 GHz. The accompanying tables show the allocations applicable to the satellites described in this report, for frequencies up to 100 GHz. Table 1 shows the first allocations, which were made in 1963. It is provided for comparison with the current allocations given in Table 2. Nations may modify the allocations table for use within their own boundaries. In the United States, this has occurred; a typical modification is the split of an allocation into government and nongovernment sub-bands. Furthermore, each nation authorizes, uses, and assigns frequencies within its own jurisdiction. In the United States, the Interdepartment Radio Advisory Committee controls federal government use of the spectrum, and the Federal Communications Commission controls other uses.

The allocations in Table 2 are separated by the service to which they apply. (Fixed-satellite service and mobile-satellite service refer to whether the terminals, not the satellites, are fixed or mobile.) Some links qualify to use allocations for two types of systems. For example, in a system that serves mobile terminals, the link between a satellite and a fixed terminal (e.g., a shore station in a maritime satellite system) may use either the fixed terminal or mobile terminal system allocations. When an allocation is not specified for uplinks or downlinks, it can be used for either or both. The third column (Region) indicates the availability of the allocation by the three ITU regions. A blank in this column indicates worldwide availability. The fourth column (Status) indi-

cates whether the allocation is primary, secondary, or by means of a footnote. This status determines the priority of the various allocations in interference questions. The fifth column (Power Limit) indicates allocations where the power density of a downlink is limited. The actual limitations are given in Table 3. The sixth column (Notes) references the notes given at the end of Table 2, which give more information about specific allocations. However, this table and its notes do not contain all of the details that are in the ITU frequency allocation table.

* * * * *

1. *Table of Frequency Allocations 10 kc/s to 40 Gc/s*, modified by the Extraordinary Administrative Radio Conference to Allocate Frequency Bands for Space Radio Communication Purposes (Geneva 1963), International Telecommunication Union, Geneva (1966).
2. *ITU Convention (Malaga-Torremolinos, 1973)*, International Telecommunication Union, Geneva (1974).
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Table 1. Initial Frequency Allocations Made in 1963

DOWNLINK, MHz	UPLINK, MHz
3400–3700	4400–4700 5725–5925
3700–4200	5925–6425
7250–7300	7975–8025
7300–7750	7900–7975 8025–8400

Table 2. Current Frequency Allocations

DOWNLINK ^a	UPLINK ^a	REGION ^b	STATUS ^c	POWER LIMIT ^d	NOTES	DOWNLINK ^a	UPLINK ^a	REGION ^b	STATUS ^c	POWER LIMIT ^d	NOTES
Fixed-Satellite Service (FSS)						7250-7375	7900-8025		F	Yes	
2500-2535 MHz		3	P	Yes	e		14.0-14.5 GHz		F		
2500-2655		2	P	Yes	e		15.4-15.7		F		
2655-2690		2	P	Yes	e	19.7-20.2			S		
2655-2690		3	P		e	20.2-21.2			P		
3400-4200			P	Yes			29.5-30.0		S		
4500-4800			P	Yes			30.0-31.0		P		
5000-5250			F		f	39.5-40.5			P	Yes	
	5725-5850	1	P				43.5-47.0		P		
	5850-7075		P				50.4-51.4		S		
7250-7750			P	Yes			66.0-71.0		P		
	7900-8400		P				71.0-74.0		P		
	10.7-11.7 GHz	1	P	Yes	g	81.0-84.0			P		
10.7-11.7			P			95.0-100.0			P		
11.7-12.3		2	P		h						
12.2-12.5		3	F	Yes	h						
12.2-12.7		2	F		i						
	12.5-12.75	1	P	Yes		Broadcasting-Satellite Service (BSS)[†]					
12.5-12.75		3	P	Yes		620-790 MHz			F		
	12.7-12.75	2	P			2500-2690			P	Yes	e
	12.75-13.25		P			11.7-12.5		1	P		
	14.0-14.5		P		j	11.7-12.2		2	F	u	u
	14.5-14.8	k,2,3	P		k	11.7-12.2		3	P		
	15.4-15.7		F		f	12.1-12.7		2	P		
	17.3-18.1		P		g	12.5-12.75		3	P		
17.7-19.7			P	Yes		22.5-23.0		2,3	P		
19.7-21.2			P			40.5-42.5			P		
	27.0-27.5	2,3	P			84.0-86.0			P		
	27.5-31.0		P			Intersatellite Service (ISS)					
31.8-33.8		3	F		1	5000-5250 MHz			F		f
	37.0-39.0	3	F		1	15.4-15.7 GHz			F		f
	42.5-43.5		P	Yes		22.55-22.55			P		
	47.2-50.2		P		m	25.25-27.5			S		v
	50.4-51.4		P			32.0-33.0			P		
	51.0-75.5		P			54.25-58.2			P		
81.0-84.0			P			59-64			P		
	92.0-95.0		P			Amateur-Satellite Service					
Mobile-Satellite Service (MSS)ⁿ						7.0-7.1 MHz			P		
235-322 MHz			F		o	14.0-14.25			P		
335.4-399.9			F		o	18.068-18.168			P		
	406.0-406.1		P		p	21.0-21.45			P		
	608-614	2	S			24.89-24.99			P		
	806-890	q,2,3	F		r	28.0-29.7			P		
	942-960	q,3	F		r	144-146			P		
1530-1544			P			435-438			F		o
1544-1545			P		s		1260-1270		F		o
1545-1559			P			2400-2450		2,3	F		o
	1610-1626.5		F			3400-3410			F		o
	1626.5-1645.5		P				5650-5670		F		o
	1645.5-1646.5		P		s	5830-5850			F		
	1646.5-1660.5		P			10.45-10.5 GHz			S		
2500-2535		3	F	Yes	r	24.0-24.05			P		
	2655-2690	3	F		r	47.0-47.2			P		
	5000-5250		F			75.5-76.0			P		
						76.0-81.0			S		

Table 2 (continued). Current Frequency Allocations

DOWNLINK ^a	UPLINK ^a	REGION ^b	STATUS ^c	POWER LIMIT ^d	NOTES
Radiodetermination-Satellite Service (RDSS)^w					
1610-1626.5 MHz		2	P		x
1610-1626.5		1,3	S		x,y
2483.5-2500		2	P	Yes	
2483.5-2500		1,3	S	Yes	y
2500-2516.5			F	Yes	y
5117-5183		2	P	Yes	
5117-5183		1,3	S	Yes	y

^a frequency band centered in these two columns may be used for both uplinks and downlinks.

^b A blank indicates worldwide applicability. Numbers indicate applicability in some regions, which are defined in the figure.

^c P = primary, S = secondary, F = footnote. Secondary uses must not interfere with primary uses nor claim protection against interference from primary uses. Footnotes imply particular restrictions; see notes. Also, secondary or footnote status usually implies a power limit.

^d Power limit: if yes, see Table 3.

^e National and regional systems only.

^f Only when used in conjunction with aeronautical radio navigation and/or aeronautical mobile service.

^g Only for broadcast satellite feeder links.

^h National and subregional systems only.

ⁱ BSS is the primary use. FSS must not cause more interference nor require more protection than the BSS.

^j May be used outside Europe for broadcast satellite feeder links.

^k Broadcast satellite feeder links only and outside Europe only.

^l Japan only and only until 31 December 1990.

^m 47.2 to 49.2 GHz is primarily for broadcast satellite feeder links.

ⁿ Some allocations restrict use to one or more of the MSS subsets: maritime-MSS, aeronautical-MSS, land-MSS.

^o Must not cause harmful interference to primary or secondary uses.

^p Solely for low-power beacons for emergency position location.

^q Only Norway and Sweden in Region 1.

^r Limited to operations within national boundaries.

^s Solely for distress and safety uses.

^t Uplinks are normally in FSS allocations.

^u FSS is the primary use. BSS limited to 53-dBW ERP. BSS must not cause more interference nor require more protection than the FSS.

^v Limited to Earth Exploration-Satellite Service.

^w Systems for position determination of mobile subscribers and for limited two-way message service; links between satellites and mobiles are below 3 GHz; links between satellites and base stations are above 3 GHz in RDSS or FSS allocations.

^x Constraints exist on use of 1610-1613.8 MHz, to protect radio astronomy.

^y Primary status in some countries.

Table 3. Maximum Power Density on the Earth's Surface, dBW/m²

ALLOCATION	ELEVATION				BANDWIDTH
	0°-20°	0°-5°	5° ≤ θ ≤ 25°	25°-90°	
620-790 MHz	-129				
2483.5-2690		-152	$-152 + \frac{3}{4}(\theta - 5)$	-137	4 kHz
3400-4200					
4500-4800		-152	$-152 + \frac{\theta - 5}{2}$	-142	4 kHz
7250-7750					
5117-5183		-159	-159	-159	4 kHz
10.7-11.7 GHz		-150	$-150 + \frac{\theta - 5}{2}$	-140	4 kHz
12.2-12.5 (region 3)					
12.5-12.75 (regions 1 and 3)		-148	$-148 + \frac{\theta - 5}{2}$	-138	4 kHz
17.7-19.7					
37.5-40.5		-115	$-115 + \frac{\theta - 5}{2}$	-105	1 MHz

Note: Density measured with the specified bandwidth. Power density limits may be exceeded on the territory of any country with its approval.

10. W. H. Bellchambers, et al., "The International Telecommunications Union and Development of Worldwide Telecommunications," *IEEE Communication Magazine*, Vol. 22, No. 5 (May 1984).

11. D. J. Withers, "The Role of CCIR Interim Working Party 4/1 in Satellite Communications," Paper 43.1, *International Conference on Communications: ICC '84* (May 1984).

12. R. E. Butler, "The Role of the ITU in the Use of the Geostationary Orbit," *Acta Astronautica*, Vol. 17, No. 6 (June 1988).

13. G. A. Coddington, Jr., "The 1989 ITU Plenipotentiary and the IFRB," *Telecommunications Policy*, Vol. 12, No. 3 (September 1988).

14. S. E. Doyle, "Space Law and the Geostationary Orbit: The ITU's WARC-ORB-85-88 Concluded," *Journal of Space Law*, Vol. 17, No. 1 (1989).

15. L. W. Barclay, "The Working of the CCIR," *Electronics and Communication Engineering Journal*, Vol. 2, No. 6 (December 1990).

APPENDIX B

TELEMETRY, TRACKING, AND COMMAND SUBSYSTEMS

All satellites have some form of telemetry, tracking, and command (TT&C) subsystem to provide control and monitoring of satellite status and to obtain data from which the satellite position can be computed. The major types of TT&C subsystems now in use by communication satellites are described here.

Intelsat/Domsat

This subsystem is used by Intelsat and by the United States domestic satellites and those domestic satellites built in the United States for other countries. This system is described as in-band, because the TT&C frequencies are within the frequency bands allocated for communications. Intelsat TT&C frequencies are near the center of the band (6168 to 6182 MHz for command and 3945 to 3955 MHz for telemetry). The Domsats use either the top or bottom 5 MHz of the communications band, i.e., 5925 to 5930 MHz or 6420 to 6425 MHz for command and 3700 to 3705 MHz or 4195 to 4200 MHz for telemetry. Domsats that use the 11- to 12- and 14-GHz bands follow the same pattern and typically assign TT&C frequencies near the upper or lower band edge. As a result of this frequency selection, most radio frequency TT&C functions are handled by communication subsystem components. During normal operations, TT&C signals are routed through communication subsystem antennas. Broad coverage omnidirectional antennas are used from launch vehicle separation through deployment and in the event of loss of signals through the communications antennas.

The basic command structure uses three tones for transmission of information, namely, one, zero, and execute tones. The information FSK modulates the tones. Some systems add one to four additional command tones, usually for analog commands or pilot tones for spin rate or antenna pointing control on dual-spin satellites. The tone set frequency modulates the command carrier. The size of the command sets varies up to about 800 commands.

The telemetry portion of the subsystem has two separate sets of equipment transmitting on separate frequencies. Each set of equipment can be commanded to handle either digital or analog telemetry. Analog telemetry frequency modulates a subcarrier. Two digital formats are used, either PCM/PSK or PAM/FM modulation of a subcarrier. In all cases, the subcarrier phase modulates the carrier.

Tracking is accomplished by sequentially modulating an uplink carrier with four tones that the satellite retransmits on a downlink. The tones vary in frequency from 35 Hz to 27.8 kHz. The range to the satellite is determined by measuring the tone phase shift during the round trip transmission. Successively higher tone frequencies provide increased accuracy, with the lower tones used to resolve ambiguities that occur with the higher tones. The ranging signal can be transmitted using the command and telemetry carriers but is typically transmitted through one of the communication transponders during on-orbit operations.

The SBS and Anik C satellites use the same TT&C subsystem. However, their communication subsystems operate in the 12- and 14-GHz bands rather than in the 4- and 6-GHz bands. They use 4- and 6-GHz transmissions through omnidirectional antennas prior to orbital deployment and 12- and 14-GHz transmissions through the communication subsystem thereafter.

Space-Ground Link Subsystem

The space-ground link subsystem (SGLS) is used for TT&C for all operational military communication satellites of the United States, Britain, and NATO. These satellites use frequencies between 7250 and 8400 MHz for communications. The SGLS is entirely separate, using 1760 to 1840 MHz for commands and 2200 to 2300 MHz for telemetry. Each satellite is assigned to one of twenty channels within these bands. In addition, most of the satellites also transmit telemetry on beacons in the 7250- to 7750-MHz communication band.

The SGLS command structure uses three tones: one, zero, and S. The S tone is transmitted during commanding whenever either of the other tones is not used. Only one tone is used at a time in an FSK format. The tones are amplitude-modulated with a synchronization signal and phase modulate the command carrier, a format designated FSK/AM/PM. The command signal transmission rate is usually 1000 baud, and the command sets vary in size from about 100 to 700 commands. All the satellites have provision for cryptographic security on the command link.

The DSCS III satellite has an additional in-band command capability. The uplink at approximately 8 GHz is received by the satellite and down-converted to the SGLS frequency and handled by the SGLS equipment.

SGLS telemetry is almost always digital, although an analog capability is possible. The typical modulation format is PCM/PSK on a subcarrier that phase modulates the carrier. Telemetry rates are 250 or 1000 bps, with from 200 to almost 1000 points monitored.

Unlike other TT&C subsystems discussed here, SGLS uses a pseudorandom binary sequence to determine range. The sequence phase modulates the command carrier and is remodulated on the telemetry carrier by the satellite. The phase shift over the round trip path is used to compute range. The sequence bit rate is 1 Mbps.

LES-8 and -9

The experimental satellites LES-8 and -9 were developed and are operated by the MIT Lincoln Laboratory for DoD. These satellites use a TT&C subsystem designed by Lincoln Laboratory.

The normal command link to a satellite is an FSK-modulated UHF carrier. Alternate command paths are via a K-band communication link, either from the ground terminal or on the crosslink from the other satellite. The commands are transmitted at about one per second, and there are about 220 commands.

The primary telemetry link is at S-band - 2.24 GHz for one satellite and 2.25 for the other. The bit rate may be either 100 bps or 10 kbps. Alternate paths are a UHF downlink or (at 100 bps only) a K-band downlink or crosslink. About 800 telemetry points are monitored.

NASA

The NASA Spaceflight Tracking and Data Network (STDN) provides TT&C services in several frequency bands. All the ATS and CTS satellites as well as the Japanese ECS and ETS-II satellites used the VHF capability. Some European satellites had STDN-compatible VHF TT&C for launch and orbital insertion and for backup during operations.

Command frequencies were in the 147- to 155-MHz band. Both PSK and FSK subcarrier formats were used, with phase modulation of the carrier. ATS 6 had a command set of 512 commands and a transmission rate of 128 or 1200 bps. The CTS had a total of 225 commands and a 1000-bps transmission rate. The Japanese ECS had a total of 168 commands and a transmission rate of 128 bps. ATS 6 had an alternative command path through a communications uplink at about 6 GHz.

Telemetry frequencies were assigned in the 136- to 138-MHz band. Typical modulation formats were PCM/PM or PCM/FM/PM. ATS 6 had two telemetry carriers at rates of about 400 bps. About 1050 telemetry points were monitored. CTS had a single carrier at 1536 bps with a total of 276 telemetry points. JECS had about 70 points and a telemetry rate of 250 bps.

The tracking scheme used multiple tones in the same manner as the Intelsat system just described above. The highest tone frequency was 20 kHz. The tones usually were transmitted at the command and telemetry frequencies. JECS, however, did its ranging through a 4- and 6-GHz satellite transponder.

The Japanese CS satellite has a TT&C subsystem with two transmission bands. One is an in-band arrangement very similar to that of Intelsat. The other is compatible with STDN's S-band equipment and uses 2.11 GHz for commanding and 2.2865 GHz for telemetry. In both cases, the command format is PCM/FSK/

PM with a rate of 128 bps. The telemetry format is PCM/PSK/PM at a rate of 250 bps.

NASA TT&C services through TDRSS use a new format, because the existing subcarrier modulation methods are inefficient for transmission through a relay satellite. In most cases, separate pseudonoise codes modulate the inphase and quadrature components of the carrier in a QPSK format. The code rate is about 3.1 Mcps. Commands are modulo two added to the code which is used for the inphase modulation. Transmitter power is split 4:1 (inphase:quadrature), so the modulation is called unbalanced QPSK. The codes are used both for ranging and to reduce the power spectral density of the signal. The same arrangement is used for low rate telemetry. Above 300 kbps, the information directly modulates the carrier without use of a pseudonoise code.

Europe

The European satellites use in-band TT&C, often with a VHF back-up. In some cases, VHF is used until orbital insertion. Their communication bands are 4 and 6 GHz in some cases, 11 and 14 GHz in others. Formats are similar or identical to the Intelsat and NASA formats already described. The data rates and number of commands and telemetry points are all within the range of 100 to 1000, the same as most of the satellites previously described.

APPENDIX C

SATELLITE BEACONS FOR PROPAGATION RESEARCH

The atmosphere can affect electromagnetic waves in several ways. Parameters that can be affected include amplitude, phase, polarization, and direction of propagation. The magnitude of each of these effects is dependent on several factors:

- Frequency, polarization, and elevation angle of the wave
- Ground terminal location and altitude
- Time of day and year
- The condition of the atmosphere

These disturbances need to be considered in the design of communication satellite systems. Therefore, they have been, and continue to be, studied in order to quantify them for use in communication link analyses. These disturbances are also studied to gain knowledge about the composition and behavior of the atmosphere. In most cases, the quantification is statistical rather than definitive; results are often specified by plotting link degradation versus the probability of exceeding the degradation.

In general, measurements of atmospheric effects that are made using horizontal paths cannot be accurately related to inclined earth-space paths. Therefore, an electromagnetic wave propagating obliquely through the atmosphere is necessary. The sun can be used for a source but only for a limited set of measurements, because it is not a coherent emitter. Some amplitude statistics can be inferred from measuring the sky noise temperature without using any signal source. However, the most satisfactory and often the only way to measure atmospheric effects is to use a satellite-based signal source. This source may be a beacon generated on the satellite or a retransmission of a signal received from a ground terminal. Occasionally, ground-based signal sources and satellite receivers are used, with the received signal parameters telemetered to the ground.

Satellite beacons and transponders used in propagation research for communications engineering purposes are discussed here. This research is concentrated in three frequency bands.

BELOW 30 MHz

Early in the space age, there was interest in low-frequency earth-space links. This interest was the result of terrestrial use of frequencies below 30 MHz for long-distance communications. Waves at these frequencies can propagate far beyond the horizon under some conditions. This feature is useful for long-distance communication with satellites at low altitudes. However, as the space age progressed, the performance and reliability of satellite-borne microwave hardware improved greatly, and the use of the synchronous equatorial orbit was perfected. These two developments eventually overshadowed interest in the lower frequencies for almost all communications applications.

The majority of experiments in this frequency range were oriented toward atmospheric and ionospheric physics. These include ORBIS (1964), OV4-1 (1966), OV1-17A (1969), and an experiment on the Space Test Program (STP) satellite S74-2 (1976). The UoSAT 1, an amateur satellite launched in 1981, had beacons at 7, 14, 21, and 28 MHz.

VHF AND UHF

Most experiments in the lower part of the VHF band, approximately 30 to 100 MHz, are scientific studies. Oscar 5, launched in 1970, had beacons at 29.45 and 144 MHz for communications measurements. The band between 225 and 400 MHz is important

for military communication satellites, yet it is characterized by significant amplitude and phase fluctuations. Therefore, several communications-related experiments have been conducted in this band. These experiments have made use of the communications transponders of several satellites including those of the ATS series and LES-5 and -6. Other measurements were made using the 254-MHz beacon on Tacsat and the 40-, 140-, and 360-MHz beacons on the ATS 6. LES-3 was a beacon satellite launched in 1965 specifically as a signal source for propagation measurements at approximately 240 MHz. The Defense Nuclear Agency had an experiment on STP satellite P76-5 launched in 1976. This experiment transmitted signals at 138 MHz, 1.24 and 2.89 GHz, and at seven frequencies in the 378- to 448-MHz band. This experiment was continued with a beacon on STP Satellite P83-1, which transmitted five of the same frequencies, and a similar beacon on Satellite P87-1.

ABOVE 10 GHz

Atmospheric effects in the 4- to 8-GHz bands are relatively mild. Measurements in this frequency range have been accomplished using the regular equipment on communication satellites. The need for more bandwidth is causing systems to be designed using allocated bands above 10 GHz. Above this frequency, both atmospheric gases and rain can have significant effects on communication links. Many experiments are being conducted, particularly to quantify the attenuation and polarization effects of rain in the 10- to 30-GHz range of frequencies.

ATS 5 was the first satellite to have equipment for propagation measurements above 10 GHz. It was launched in 1969 and had an experiment with a 31.65-GHz uplink and a 15.3-GHz downlink. ATS 6 followed with a 13- and 18-GHz uplink experiment and a 20- and 30-GHz downlink experiment. The uplink experiment included terminals sited to study diversity as a means to overcome rain loss. The downlink experiment had three modes: an unmodulated carrier, a 1.4-GHz wide line spectrum, or retransmission of a modulated 6-GHz uplink. These experiments were used for several years in the United States, and for one year in Europe, while ATS 6 was stationed at 35°E longitude. The AT&T Comstar satellites had beacons at 19.04 and 28.56 GHz. The 28-GHz signal was modulated to produce sidetones at either ± 264.4 or ± 528.9 MHz, and the 19-GHz signal was switched between orthogonal linear polarizations at a 1-kHz rate. ETS-II was a Japanese beacon satellite that operated for more than one year transmitting at 1.7, 11.5, and 34.5 GHz.





























Several experimental communication satellites have been built to operate in the 10- to 30-GHz range. All are used to some extent in propagation tests. Sirio was used for propagation measurements with both uplink and downlink signals or for communication tests. It operated at 11.6 and 17.4 GHz. The OTS operated in the 12- and 14-GHz bands. Of its five transponders, one was dedicated to propagation studies. Propagation measurements also have been made using the Canada/NASA CTS and are included in the experimental programs of the Japanese BS, CS, and ECS, the European Olympus, the Italian Italsat, Aussat B, and the NASA ACTS. These satellites cover the allocated frequency bands at 11-12, 14, 18-20, and 28-30 GHz. Italsat also has beacons at 40 and 50 GHz to begin experiments in those frequency bands.

GLOSSARY

BLOCK DIAGRAM SYMBOLS

The communication subsystem block diagrams included for most of the satellites herein are relatively simple; they primarily show antennas and duplexers, amplification, frequency conver-

sion, and channel switching and combining. The following symbols are common to all the block diagrams; specialized symbols are defined in the figure in which they occur.

	Amplifier (type not specified)		Limiter
	Parametric amplifier		Frequency in MHz
	Transistor amplifier		Channel numbers
	Tunnel diode amplifier		Bandwidth
	Traveling wave tube amplifier		Indicates input to mixer from local oscillator
	Mixer		Switch network – connects the two inputs to any two distinct outputs
	Switch: equivalent to 		Switch network – connects any two inputs to distinct outputs
	Switch: equivalent to 		A switch matrix, with more than three inputs or outputs, which can form many different one-to-one interconnections of its input and output ports; excess input or output ports are terminated
	Channel combiner		Antenna beam forming network
	Four-port hybrid		Antenna (any type)
	Duplexer		Parabolic reflector
	Triplexer		Feed horn (or array of horns)
	Power splitting network		
	Filter		

GLOSSARY

ABBREVIATIONS AND ACRONYMS

ACTS	Advanced Communications Technology Satellite (NASA)	CS	Japanese communication satellite
ADCSP	Advanced Defense Communication Satellite Program	CTS	Communications Technology Satellite (known as Hermes in Canada)
AFSATCOM	Air Force Satellite Communications	CW	continuous wave
AM	amplitude modulation	DATS	Despun Antenna Test Satellite (DoD)
Amsat	Radio Amateur Satellite Corporation	DARPA	Defense Advanced Research Projects Agency
AMSC	American Mobile Satellite Corporation (United States)	dB	decibel
APPLE	Ariane Passenger Payload Experiment (India)	DBS	direct broadcast satellite (or system)
Arabsat	Arab Satellite Communications Organization	dBW	decibel watt
ARPA	Advanced Research Projects Agency (now DARPA)	DC, dc	direct current
ASC	American Satellite Corporation	DCA	Defense Communications Agency
ASEAN	Association of Southeast Asian Nations	DCP	data collection platform
AT&T	American Telephone and Telegraph Company	DFS	Deutsche Fernmeldesatellit (German Telecommunications Satellite)
ATS	Applications Technology Satellite (NASA)	DFVLR	Deutsche Forschungs und Versuchsanstalt für Luft-und Raumfahrt (Germany)
AW	Advanced Westar	DNA	Defense Nuclear Agency
BAPTA	bearing and power transfer assembly	DoD	Department of Defense
BEAR	Beacon Experiment and Auroral Research	domsat	domestic communications satellite
BFN	beam forming network	DPSK	differential phase shift keying
bps	bits per second	DQPSK	differential quadriphase shift keying
BS (or BSE)	Medium-Scale Broadcasting Satellite for Experimental Purpose (Japan)	DSCS	Defense Satellite Communication System
BSB	British Satellite Broadcasting, Ltd.	DSI	digital speech interpolation
BSS	Broadcasting-Satellite Service	EBU	European Broadcasting Union
CAS	Cooperative Applications Satellite	EC	earth coverage
C-band	3 to 7 GHz (in satellite communications)	ECS	European Communication Satellite
CCIR	from the French for International Radio Consultative Committee	EHF	extremely high frequency (in science, 30-300 GHz; in satellite communications, approximately 20 - 50 GHz)
CDAS	command and data acquisition station	EIRP	effective isotropic radiated power
CDMA	code division multiple access	ERP	effective radiated power
CFDM	companded frequency division multiplexing	ESA	European Space Agency
CIFAS	Consortium Industriel Franco-Allemand pour le Satellite Symphonie (France-Germany)	ESRO	European Space Research Organization
CML	a joint venture of Comsat General, MCI, and Lockheed Aircraft, called CML Satellite Corporation	ETS	Engineering Test Satellite (Japan)
CNES	Centre National d'Etudes Spatiales (France)	Eutelsat	European Telecommunications Satellite Organization
CNET	Centre National d'Etudes Telecommunications (France)	FCC	Federal Communications Commission
CNR	Consiglio Nazionale della Ricerca (Italian National Research Council)	FDM	frequency division multiplexing
Comsat	Communications Satellite (Corporation)	FDMA	frequency division multiple access
CONUS	Continental United States	FEP	FLTSATCOM EHF package
COSPAS	Cosmicheskaya Sistemya Poiska Avariynich Sudov (Russian for Space System for the Search of Distressed Vessels)	FET	field effect transistor
		FLTSATCOM	Fleet Satellite Communications (DoD)
		FM	frequency modulation
		FSK	frequency shift keying
		FSS	Fixed-Satellite Service
		FTV	frontier television (terminal) (Canada)
		GDA	gimbaled dish antenna

GE	General Electric	L-Sat	Large Telecommunications Satellite (Europe) (now Olympus)
GEOS	Geodynamics Experimental Ocean Satellite	LUT	local user terminal (Sarsat-Cospas)
GGTS	Gravity-Gradient Test Satellite	MA	multiple access (TDRSS)
GHz	gigahertz (1 GHz = 1000 MHz)	Maesat	multiple access communications satellite (DARPA)
GLOMR	Global Low Orbiting Message Relay	Marecs	Maritime European Communication Satellite
GOES	Geostationary Operational Environmental Satellite	Marots	Maritime Orbital Test Satellite
GPS	Global Positioning System	MB	multibeam
GSat	GTE Satellite Corporation	Mb	megabit
G/T	gain-to-noise-temperature ratio	MBA	multibeam antenna
GTE	General Telephone and Electronics	Mbps	megabits per second
HCI	Hughes Communications, Inc.	MCI	Microwave Communications, Inc.
HEMT	high electron mobility transistor	MCS	maritime communication subsystem (Intelsat V)
HF	high frequency (in science, 3 to 30 MHz)	MESH	a west European industrial consortium
HR	Heavy route (terminal) (Canada)	MHz	megahertz
H-Sat	Heavy Communications Satellite (Europe) (now Olympus)	MIT	Massachusetts Institute of Technology
Hz	hertz	MMD	mean mission duration
IBS	Intelsat Business Service	MMW	millimeter wave
IDCSP	Initial Defense Communication Satellite Program	MSS	Mobile-Satellite Service
IDR	Intermediate Data Rate (Intelsat)	MTBF	mean time before failure
IDSCS	Initial Defense Satellite Communication System	MTTF	mean time to failure
IF	intermediate frequency	NASA	National Aeronautics and Space Administration
IFRB	International Frequency Registration Board	NASDA	National Space Development Agency (Japan)
IMO	Intergovernmental Maritime Organization	NATO	North Atlantic Treaty Organization
Inmarsat	International Maritime Satellite Organization	NB	narrow band
Intelsat	International Telecommunication Satellite Organization	NiCd	nickel cadmium (battery)
ISRO	Indian Space Research Organization	NiH ₂	nickel hydrogen (battery)
ISS	Intersatellite Service	nmi	nautical mile
ITU	International Telecommunication Union	NOAA	National Oceanic and Atmospheric Administration
ITV	instructional television (ATS 6)	NTC	northern telecommunication (terminal) (occasionally named medium route) (Canada)
IUS	Inertial Upper Stage	NTT	Nippon Telegraph and Telephone Corporation
JAS	Japanese amateur satellite	NTV	network television (terminal) (Canada)
JCSat	Japan Communications Satellite, Inc.	OFT	orbital flight test
JECS	Japanese Experimental Communication Satellite	ORBIS	Orbiting Radio Beacon Satellite
K	kelvin	Oscar	orbiting satellite carrying amateur radio
K-band	10 to 31 GHz (in satellite communications)	OTS	Orbital Test Satellite (Europe)
Ka-band	17 to 21 GHz and 27 to 31 GHz (in satellite communications)	OV	orbiting vehicle
Ka-ISL	Ka-band Intersatellite Link	PAM	perigee assist motor; pulse amplitude modulation
kbps	kilobits per second	PBS	Public Broadcasting Service
kHz	kilohertz	PCM	pulse code modulation
KSA	K-band single access (TDRSS)	PEACESAT	Pan Pacific education and communication experiments by satellite
Ku-band	10.7 to 14.5 GHz (in satellite communications)	PKM	perigee kick motor
kWh	kilowatt hours	PLACE	position location and aircraft communication experiment (ATS 6)
LAM	liquid apogee motor	PM	phase modulation
L-band	1.5 to 1.7 GHz (in satellite communications)	PNG	Papua New Guinea
LES	Lincoln Experimental Satellite		
LHCP	left-hand circular polarization		

PSK	phase shift keying	SSA	S-band single access (TDRSS)
QPSK	quadruphase shift keying	SSMA	spread spectrum multiple access
RARC	Regional Administrative Radio Conference	SSPA	solid-state power amplifier
RCA	Radio Corporation of America	SSS	Strategic Satellite System (DoD)
RCS	reaction control subsystem	SS-TDMA	satellite-switched TDMA
RDSS	Radiodetermination-Satellite Service	STC	Satellite Television Corporation
RF	radio frequency	STDN	Spaceflight Tracking and Data Network (NASA)
RFI	radio frequency interference	STEP	Satellite Telecommunications Experimental Project (India)
RHCP	right-hand circular polarization	STGT	Second TDRSS Ground Terminal
rpm	revolutions per minute	STP	Space Test Program (United States Air Force)
RS	amateur radio satellites (Soviet Union)	STW	Shiyan Tongxin Weixing (experimental communications satellite) (China)
RTG	radioisotope thermoelectric generator	Syracuse	System of Radio-Communication Using a Satellite (France)
RTV	remote television (terminal) (Canada)	Tacsat	Tactical Communications Satellite (DoD)
SAMSO	Space and Missile Systems Organization (United States Air Force) (now Space Systems Division)	TCSJ	Telecommunication Satellite Corporation of Japan
SAMT	State-of-the-Art Medium Terminal (DSCS)	TDA	tunnel diode amplifier
SARSAT	search and rescue satellite-aided tracking	TDF	Telediffusion de France
S-band	1.7 to 2.7 GHz (in satellite communications)	TDMA	time division multiple access
SBS	Satellite Business Systems	TDRS(S)	Tracking and Data Relay Satellite (System) (NASA)
SBTS	Sistema Brasileiro de Telecomunicacoes por Satellite	TETR	(see TTS)
SCC	Space Communications Corporation (Japan)	TMI	Telesat Mobile, Inc. (Canada)
SCCE	Satellite Configuration Control Elements	TR	thin route (terminal) (Canada)
SCF	Satellite Control Facility (United States Air Force) (now SCN)	TRUST	television relay using small terminals (ATS 6)
SCN	Satellite Control Network (United States Air Force)	TT&C	telemetry, tracking, and command
SCORE	Signal Communication by Orbiting Relay Equipment	TTS	Test and Training Satellite
SCPC	single channel per carrier	TV	television
SCT	single channel transponder (AFSATCOM)	TWT	traveling wave tube
SDRN	Satellite Data Relay Network (Soviet Union)	TWTA	traveling wave tube amplifier (TWT plus power supply)
SECS	small experimental communication satellite	UFO	UHF follow-on
SES	Société Européenne des Satellites (Luxembourg)	UHF	ultrahigh frequency (in science, 300-3000 MHz; in satellite communications, 235-400 MHz)
SGLS	Space-Ground Link Subsystem (United States Air Force)	UoSAT	University of Surrey (England) satellite
SHF	super high frequency (in science, 3-30 GHz; in satellite communications, typically 7-8.4 GHz)	VAS	Visible Atmospheric Sounder
Sirio	from the Italian words for Italian Industrial Research Satellite Organization	VHF	very high frequency (in science, 30-300 MHz; in satellite communications usually 137-150 MHz)
SITE	satellite instructional television experiment (ATS 6)	VSAT	very small aperture terminal
SMS	Synchronous Meteorological Satellite	WARC	World Administrative Radio Conference
SMSK	serial minimum shift keying	WB	wide band
SPADE	single channel per carrier, pulse code modulation, multiple access, demand-assigned equipment	WSGT	White Sands Ground Terminal (TDRSS)
SPCC	Southern Pacific Communications Corporation	X-band	7.2 to 8.4 GHz (in satellite communications)

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This bibliography is a supplement to the references cited at the end of the satellite descriptions. Some items are included here because of their general nature—useful for an overview of communication satellites, but not specific enough to be referenced in the description of a particular satellite. Other items are included as introductory and representative information on subjects related to the satellite descriptions contained in the report. Each item is given only once, hence it may be necessary to refer to more than one section of the bibliography as well as the references in the report for a broad collection of published material on a given subject. The bibliography covers a wide range of subjects arranged in the following order:

Satellites and Systems

- Historical
- General (through 1985)
- General (after 1985)
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- Mobile
- Broadcasting
- Europe
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- Advanced Concepts
- Geostationary Platforms
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Applications

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Ground Terminals

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- Small and Transportable
- Military
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Modulation and Multiple Access

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- Multiple Access

TDMA

Single Channel per Carrier and Demand Assignment

Speech Encoding

Packet Networks

Orbit and Spectrum Use

- General
- ITU Conferences
- Technical Studies

Link and Network Engineering

- Link and Network Simulation
- Link and Budgets
- Analysis of Transmission Impairments
- Atmospheric Propagation
- Resource Utilization and Capacity Optimization
- Network Monitoring and Control
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- VSAT Networks

Satellite Engineering

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- Launch Vehicles
- Orbit Determination and Control
- Satellite Monitoring and Control

Satellite Hardware

- Communications Technology
- Antennas
- Receivers
- Processors and Switches
- Transmitters
- Intersatellite Links
- Spacecraft Subsystems

Other Topics

- Policy and Economics
- Regulatory and Legal

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